

NOAA COASTAL CHANGE ANALYSIS PROGRAM (C-CAP): GUIDANCE FOR REGIONAL IMPLEMENTATION

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DOCUMENT CONTAINS DATED MATERIAL. The information contained within this document, *NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation (1995)*, provides technical and historical background on C-CAP. Since the publication date, technological and programmatic advancements have occurred. The program itself, for instance, is now part of the NOAA Coastal Services Center's Coastal Remote Sensing program. This document remains available for public consumption because it also provides valuable information on change detection algorithms, classification schemes, and the use of remote sensing for documenting regional coastal changes. For additional information about C-CAP products, please review the NOAA Coastal Services Center's Coastal Remote Sensing Web site (www.csc.noaa.gov/crs/) or contact the Center by e-mail at csc@csc.noaa.gov.

NOAA COASTAL CHANGE ANALYSIS PROGRAM (C-CAP): GUIDANCE FOR REGIONAL IMPLEMENTATION

NOAA Technical Report NMFS 123 Department of Commerce

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Acknowledgments

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Preface

This unique document represents a first attempt to develop guidelines that will allow researchers and resource managers alike to quantitatively monitor changes that are occurring in the abundance of emergent and submergent wetlands and adjacent uplands in coastal regions. Such information is essential in order to effectively relate changes in coastal land use to changes in the productivity of estuaries and coastal waters on a regional scale.

This is a document that was developed from input from approximately 200 research scientists and resource managers that attended five regional workshops and several topical interagency meetings. Thus, we believe it represents a general consensus of how to approach the issue of quantifying land cover and wetland change in coastal regions. Because improvement in existing technologies and in our understanding of how to measure habitat change on a regional scale undoubtedly will occur, we intend to update this document periodically. These updates, however, require time to publish, so anyone planning to use these guidelines should contact the corresponding author to obtain drafts of any revised chapters that have not yet been published.

Finally, I would like to express my appreciation to the authors for their fine effort and to Dr. Don Scavia, Director of NOAA's Coastal Ocean Program, for his support, both financial and moral, during the development of this document. I believe we have made a significant step in addressing an important coastal issue.

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Executive Summary

The Coastal Change Analysis Program¹ (C-CAP) is developing a nationally standardized database on land cover and habitat change in the coastal regions of the United States. C-CAP is part of the Estuarine Habitat Program (EHP) of NOAA's Coastal Ocean Program (COP). C-CAP inventories coastal submersed habitats, wetland habitats and adjacent uplands and monitors changes in these habitats on a 1 to 5 year cycle. This type of information and frequency of detection are required to improve scientific understanding of the linkages of coastal and submersed wetland habitats with adjacent uplands and with the distribution, abundance and health of living marine resources. The monitoring cycle will vary according to the rate and magnitude of change in each geographic region. Satellite imagery (primarily Landsat Thematic Mapper), aerial photography, and field data are interpreted, classified, analyzed, and integrated with other digital data in a geographic information system (GIS). The resulting land cover change databases are disseminated in digital form for use by anyone wishing to conduct geographic analysis in the completed regions.

C-CAP spatial information on coastal change will be input to conceptual and predictive models to support coastal resource policy planning and analysis. C-CAP products will include: 1) spatially registered digital databases and images, 2) tabular summaries by state, county, and hydrologic unit, and 3) documentation. Aggregations to larger areas (representing habitats, wildlife refuges, or management districts) will be provided on a case by case basis. Ongoing C-CAP research will continue to explore techniques for remote determination of biomass, productivity, and functional status of wetlands and will evaluate new technologies (e.g. remote sensor systems, global positioning systems, image processing algorithms) as they become available. Selected hardcopy land cover change maps will be produced at local (1:24,000) to regional scales (1:500,000) for distribution. Digital land cover change data will be provided to users for the cost of reproduction.

Much of the guidance contained in this document was developed through a series of professional workshops and interagency meetings which focused on (a) coastal wetlands and uplands; (b) coastal submersed habitat including aquatic beds; (c) user needs; (d) regional issues; (e) classification schemes; (f) change detection techniques; and (g) data quality. Invited participants included technical and regional experts and representatives of key state and federal organizations. Coastal habitat managers and researchers were given an opportunity for review and comment.

This document summarizes C-CAP protocols and procedures which are to be used by scientists throughout the United States to develop consistent and reliable coastal change information for input to the

C-CAP nationwide database. It also provides useful guidelines for contributors working on related projects. It is considered a working document subject to periodic review and revision.

1 Formerly known as the "CoastWatch Change Analysis Program"

Chapter 1. Introduction

The Coastal Region Management Problem

The conterminous United States lost 53 percent of its wetlands to agricultural, residential, and/or commercial land use from the 1780s to 1980s (Dahl 1990). Oil spills occurring throughout the world continue to devastate coastal wetlands (Jensen et al. 1990; Narumalani et al. 1993). Sea level has risen approximately 130 meters in the past 17,500 years. More abundant "greenhouse" gases in the atmosphere may be increasing the Earth's average temperature (Clarke and Primus 1990) and may, yet again, accelerate the global sea level rise, eventually inundating much of today's coastal wetlands (Lee et al. 1992). Unfortunately, current projections for U.S. population growth in coastal regions suggest accelerating losses of wetlands and adjacent habitats, as waste loads and competition for limited space and resources increase (U.S. Congress 1989). Coastal wetlands and submersed habitats are being destroyed by erosion, dredge and fill, impoundments, toxic pollutants, eutrophication, and (for submersed habitats) excessive turbidity and sedimentation. Most of marine finfish and shellfish depend on these coastal habitats for their survival. Salt marsh grasses, mangroves, macroalgae, and submersed grasses and forbs are essential as nourishment and as protection for spawning, raising juveniles, and hiding from predators. Continued loss of these wetlands may lead to the collapse of coastal ecosystems and associated fisheries. Documentation of the loss or gain of coastal wetlands is needed now for their conservation and to effectively manage marine fisheries (Haddad and Ekberg 1987; Kean et al. 1988; Haddad and McGarry 1989; Kiraly et al. 1990). Submersed grasses and forbs include high salinity requiring seagrasses and other species of submersed rooted vascular plants that tolerate or require low salinity water. Submersed grasses and forbs may be a crucial indicator of water quality and overall health of coastal ecosystems (Dennison et al. 1993). Submersed vegetation has the additional requirement of living at photic depths and therefore is particularly sensitive to water clarity (Kenworthy and Haunert 1991). Change (increase or decrease in areal extent, movement, consolidation or fragmentation, or qualitative change) in submersed habitat may be a sensitive integrator of overall water quality and potential for change in fisheries productivity. Submersed rooted vascular (SRV) aquatic beds define habitat critical for the support of many recreational and sport fisheries (Ferguson et al. 1980; Klemas et al. 1993; Phillips 1984; Thayer et al. 1984; Zieman 1982; Zieman and Zieman 1989). Changes in uplands, wetlands, and submersed habitats are rapid and pervasive. Hence, effective management requires frequent monitoring of coastal regions (at least twice per decade).

It has long been suspected that a crucial factor in the observed decline of fisheries in most coastal regions is the declining quantity and quality of habitat. Land cover change is a direct measure of quantitative habitat loss or gain. For many marine fisheries the habitats (ie. land covers) of greatest importance are saltmarsh and seagrass. Other fisheries, such as salmon, depend on a variety of habitats that may include upland, as well. Land cover change also is a direct measure of increases or decreases in sources of pollution, sedimentation, and other factors that determine habitat quality. Increases in developed land, for

example, are accompanied by land disturbance that increases erosion and sedimentation and by hydrologic alteration that increases runoff. Similarly, cultivated land is associated with fertilizer and pesticide inputs to the land and ultimately to the marine environment. Hence, land cover change is linked to habitat quantity and quality.

The NOAA Coastal Change Analysis Program (C-CAP) Solution

For these reasons, the National Oceanic and Atmospheric Administration (NOAA) Coastal Ocean Program initiated the Coastal Change Analysis Program (C-CAP), a cooperative interagency and state/federal effort to detect coastal upland and wetland land cover and submersed vegetation and to monitor change in the coastal region of the United States (Cross and Thomas 1992; Haddad 1992). The project utilizes digital remote sensor data, in situ measurement in conjunction with global positioning system systems, and geographic information system (GIS) technology to monitor changes in coastal wetland habitats and adjacent uplands. Landsat multispectral scanner (MSS) data, Landsat Thematic Mapper (TM) data, and SPOT high resolution visible (HRV) data have been used successfully to detect major categories of wetlands (Haddad and Harris 1985; Lade et al. 1988; Jensen et al. 1993b). However, they have not been used previously to map or monitor wetlands for regional or national coverage. The use of satellite imagery for mapping wetlands provides a number of advantages over conventional aerial photographs including timeliness, synopticity, and reduced costs. While aerial photography may be appropriate for high resolution cartography, satellite imagery is better suited and less costly for rapid, repeated observations over broad regions (Bartlett 1987; Klemas and Hardisky 1987; Haddad and Harris 1985; Ferguson et al. 1993). Although the program will stress the use of satellite imagery, particularly for coastal wetlands and adjacent uplands, aerial photography or a combination of photography and satellite imagery (TM or SPOT) will be used for mapping SRV (Orth and Moore 1983) and certain other habitats as suggested by Patterson (1986) and Lade et al. (1988). A methodology to photographically observe, analyze and display spatial change in habitat defined by the presence of SRV was a prerequisite to a nationwide change detection effort (Thomas and Ferguson 1990).

The C-CAP nationally standardized database will be used to monitor land cover and habitat change in the coastal region of the United States (Thomas and Ferguson 1990; Thomas et al. 1991) and to improve understanding of coastal uplands, wetlands (e.g. salt marshes), and submersed habitats (e.g. seagrass) and their linkages with the distribution, abundance, and health of living marine resources. Coastal regions of the U.S. will be monitored every 1 to 5 years depending on the anticipated rate and magnitude of change in each region and the availability of suitable remote sensing and in situ measurements. This monitoring cycle will provide feedback to habitat managers on the success or failure of habitat management policies and programs. Frequent feedback to managers will enhance the continued integrity or recovery of coastal ecosystems and the attendant productivity and health of fish and other living marine resources at minimal cost. In addition, the geographical database will allow managers and scientists to evaluate and ultimately to predict cumulative direct and indirect effects of coastal development on wetland habitats and living marine resources. Initially, C-CAP products will document current land cover distribution and the change that has occurred in the recent past. The database, increasing with each subsequent monitoring cycle, will be an invaluable baseline resource for research, evaluation of local, state and federal wetland management strategies, and construction of predictive models. C-CAP directly supports NOAA's responsibilities in estuarine and marine science, monitoring, and management legislated in the Fish and Wildlife Coordination Act; the Magnuson Fishery Conservation and Management Act; the Coastal Zone Management Act; the Clean Water Act; the Marine Protection, Research and Sanctuaries Act; and the National Environmental Policy Act. Land cover change data are essential to the implementation of a "No

Net Loss" wetlands policy.

A large community of managers, scientists, and users were involved in developing a C-CAP protocol at the national level. Guidance in this document was derived from a series of professional workshops and interagency working group meetings which focused on:

- user needs
- upland, wetland, and water classification schemes
- regional boundary issues
- cartographic datum and data structures
- selection of appropriate satellite imagery and aerial photography
- field work and field verification methods
- satellite remote sensing of coastal wetlands and uplands
- photo interpretation of coastal submersed habitat including seagrasses
- calibration among regions and scenes
- classification and change detection algorithms
- geographic information processing and analysis
- regional ecological modeling
- quality assurance and control
- product availability and distribution research issues.

Approximately 40 scientists and environmental managers attended each major regional workshop held in the Southeast, Northeast, Pacific Coast, and Great Lakes with approximately 200 individuals participating in all workshops and special meetings. The community of users and providers of coastal habitat information were given an opportunity for review and comment. A detailed list of workshops is found in Appendix 11.4.

While C-CAP is national in scope, it is based on procedures also applicable at local and regional levels. Much of the content of this document is based on C-CAP sponsored research conducted at the regional level. For example, Klemas et al. (1993) of the College of Marine Studies at the University of Delaware developed the "C-CAP Coastal Land Cover Classification System" by investigating existing upland and wetland classification systems and then synthesizing a new system practical at the regional level. Dobson and Bright (1991, 1992, 1993) of the Oak Ridge National Laboratory (ORNL) developed a regional prototype for inventorying uplands and wetlands in the Chesapeake Bay Region. Jensen et al. (1993a) evaluated various change detection algorithms for inland and coastal wetland environments near Charleston, South Carolina. Ferguson et al. (1993) developed a regional prototype to inventory SRV in North Carolina based on protocols developed by the Beaufort Laboratory, Southeast Fisheries Science Center, National Marine Fisheries Service. Khorram et al. (1992) investigated methods of seamlessly integrating multiple region C-CAP databases.

The C-CAP protocol continues to evolve and improve. For example, projects underway in 1993 include analysis of the effects of tidal stage on remote sensing classification, change detection accuracy assessment, refined techniques for classification of forested wetlands, and advanced change detection techniques (Appendix 11.5). Research continues on functional health indicators (e.g., biomass, productivity), plant stress (e.g., mangrove freeze), new data collection instruments, and regional ecological modeling. Thus, C-CAP will continue to have a strong research and development component

to improve and refine its operational techniques.

C-CAP's National Scope and Regional Implementation

No single federal or state organization will collect all the information residing in the C-CAP database. Instead, regional inventories will be completed by regional experts following C-CAP guidelines. Therefore, it is important to define the logic used to specify a C-CAP region. First, regional boundaries must coincide with NOAA/NMFS Regions, including:

- Northeast - Virginia through Maine including the Great Lakes
- Southeast - Texas through N. Carolina, U.S Virgin Islands, Puerto Rico
- Northwest - Oregon, Washington, and Alaska
- Southwest - California, Hawaii, Midway Islands, Wake, Guam, Mariana Islands, American Samoa, Johnston Atoll, Trust Territory of the Pacific Islands, Baker and Howland Islands, and Jarvis Island.

Coastal regions may be further subdivided, as appropriate, on the basis of state and other administrative boundaries or ecoregions as defined, for example, by Omernick (1987).

The boundary should encompass coastal watersheds plus offshore coral reefs, algae, and seagrass beds in the photic zone. In keeping with the goals of C-CAP and anticipated funding constraints the recommended approach is to designate (1) standard coverage limits for general application, and (2) extended coverage limits for regions with special needs. Standard coverage will utilize biological and other geographical boundaries appropriate to the needs of specified C-CAP users identified through the protocol workshops. Extended coverage will be defined for each regional project in collaboration with states and other regional organizations. NOAA will make every effort to identify and accommodate research, conservation, management, and other needs that rely on wetland maps and data. Regional projects will be designed to identify special needs that may require extended coverage and to suggest sources of funds to support the additional cost of extended coverage.

The Estuarine Drainage Area (EDA), defined by NOAA/National Ocean Service (NOS) as the "land and water component of an entire watershed that most directly affects an estuary", is an appropriate standard coverage area for C-CAP. For the purposes of this program, all U. S. coasts are or will be defined as part of an Estuarine Drainage Area. The boundary of each EDA basin will be defined to be consistent with USGS Hydrologic Units and codes.

The Estuarine Drainage Boundary as defined by NOAA/NOS is considered a standard inland boundary for C-CAP regional projects. Regional analysts may employ C-CAP protocols upstream, but C-CAP funding is not intended for coverage beyond the EDA. However, C-CAP funding may be used to purchase satellite scenes that extend beyond the EDA if they are necessary to cover the coastal region. Functional definitions, such as "limits of tidal influence," may be employed in response to local situations justified by local user communities and local/regional experts on a coastal region by region or estuary by estuary basis. Regional analysts should be aware of local, state, and Federal rights and responsibilities and should seek inter-governmental and interagency cooperation. Because C-CAP interests include the effects of eutrophication due to development of uplands, information from outside the EDA may be justified in high order streams that extend beyond the coastal region. In this case, the point where the river enters the region will be defined as a point source for inputs.

The offshore boundary of each region is defined as the seaward extent of wetlands, seagrass, coral, or other submersed habitat detectable using remote sensing systems. The functional definition of "limits of detection" normally will be based on satellite and aerial sensors and will vary within and among regions. Both the "limits of detection" and the actual bathymetric range of SRV are based on light attenuation and, thus, will not be a consistent bathymetric contour even within a single region.

Overlap of regions, consistent with TM scene boundary overlap, is preferred so that analysts may calibrate results from neighboring regions. A healthy exchange between neighboring regional analysts could reconcile differences, not only in the area of overlap, but in signature identification across both regions. Each regional project team will be responsible for calibrating the relationship between remotely sensed spectral information and other information such as field measurements of biomass and photosynthetic rates. Historically, such measurements have focused on relatively few of the many species, habitats, and land cover types of significance in the coastal region. Analysts should also ensure that protocols originally developed for northern temperate latitudes are modified sufficiently to serve well in tropical areas of the Southern U.S., Caribbean, and Pacific Ocean, and in the Arctic areas of Alaska. It will be necessary, for example, to use different methods and sensors for coral reefs than for wetlands. Similarly, the identification of Arctic muskeg may require different methods and sensors from those used to identify temperate, herbaceous wetland.

Change Detection Every 1 to 5 Years

The frequency of change detection is a crucial issue. For most regions in the United States, the base year (sometimes referred to as Date 1 in the diagrams or T_b) should be the most recent year for which acceptable satellite imagery for uplands and wetlands or aerial photographs for submersed habitat can be obtained, and for which sufficient in situ information is available to conduct an error evaluation. Exceptions may occur in regions where cloud cover is a perennial problem or where other considerations favor aerial photographs over satellite imagery. The choice of the second date of imagery (Date $n-1$ or $n+1$) may be more flexible. It may be desirable to choose a date one to five years earlier than the base period to capture recent changes in coastal habitats. Plans should then be made for another change analysis no later than five years after the base time. However, plans may be altered abruptly when natural or human-induced events, such as hurricanes and oil spills, occur.

Five years is the recommended frequency of change detection for most regions, but shorter periods may be necessary in regions undergoing rapid economic development or affected by catastrophic events. Longer periods may be necessary where funds are limited or where change is exceptionally slow. Regional analysts are advised to evaluate rates of change and explicitly recommend the base year and change period as a part of each regional project proposal. Unfortunately, remotely sensed data obtained specifically for other purposes (e.g. urban analysis, forest inventory, etc.) often are not suitable for use in C-CAP. Aquatic beds, and even coastal wetlands, may not be identifiable on aerial photography obtained for other purposes.

The Need for Standardization and Guidelines

C-CAP desires to create a synoptic, digital database of coastal wetland and upland land cover by class for a base time period and to identify change between the base period and other time periods. The use of satellite remote sensing to inventory uplands and wetlands, conventional aerial photography to inventory submerged lands, and geographic information systems (GIS) to analyze the data are important elements

of the C-CAP methodology. However, the goal of completing an accurate change detection product overrides any given technical consideration. Therefore, timely high-quality information whether from aerial photographs, topographic maps, field experience or other sources may be used in the preparation of the C-CAP products if appropriate guidelines are followed.

By standardizing procedures at the national level this document will benefit not only C-CAP but also coastal management research conducted by other state and federal agencies. C-CAP desires to facilitate the exchange of standardized data among programs, decrease duplication, and improve the quality and utility of decision support for wetlands policy, management, and research activities. All data accepted for inclusion and eventual distribution in the C-CAP database must adhere to the protocol described in this manual. The protocol is designed to allow for flexibility in the use of elements of the classification scheme, choice of remote sensor data, classification and change detection procedures, and other key elements that vary regionally. However, potential users must adhere to the protocol in order to maintain high quality information in the C-CAP database. Coastal land cover change databases derived independently from C-CAP will be considered for dissemination as C-CAP products if originating organizations can document compliance with C-CAP protocol and data quality standards.

General Steps Required to Conduct Regional C-CAP Projects

The general steps required to conduct regional C-CAP change detection projects using satellite remotely sensed data are summarized in **Table 1**. This document is organized according to these specific requirements, and in certain instances provides step-by-step instructions to be used when conducting regional projects. One of the first requirements of regional participants is to precisely identify land cover classes of interest to be monitored and eventually placed in the C-CAP change detection database. This must be performed in conjunction with an appropriate classification scheme. Unfortunately, no existing standardized classification scheme was suitable for all C-CAP requirements. Therefore, great effort went into the development of the C-CAP Coastal Land Cover Classification System which can be used to inventory uplands and wetlands using satellite remote sensor data as well as SRV using metric aerial photography.

Table 1. General steps required to conduct regional C-CAP change detection projects to extract upland and wetland information using satellite remote sensing systems.

-
- State the regional change detection problem
 - Define the region
 - Specify frequency of change detection (1 to 5 years)
 - Identify relevant classes of the C-CAP Classification System
 - Consider significant factors when performing change detection
 - Remote sensing system considerations
 - Temporal resolution
 - Spatial resolution
 - Spectral resolution
 - Radiometric resolution
 - The preferred C-CAP remote sensing system
 - Environmental considerations

- Atmospheric considerations
 - Soil moisture conditions
 - Vegetation phenological cycle characteristics
 - Tidal Stage
 - Conduct image processing of remote sensor data to extract upland wetland information
 - Acquire appropriate change detection data
 - Base year (Time b)
 - Subsequent year (Time b-1 or b+1)
 - Preprocess the multiple-date remotely sensed data
 - Geometric rectification
 - Radiometric correction (normalization)
 - Select appropriate image classification logic
 - Supervised
 - Unsupervised
 - Hybrid
 - Perform change detection using GIS algorithms
 - Highlight selected classes using change detection matrix
 - Generate change map products
 - Compute change statistics
 - Conduct quality assurance and control
 - Assess spatial data quality
 - Assess statistical accuracy
 - Individual date classification
 - Change detection products
 - Distribute C-CAP Results
 - Digital products
 - Analog (hardcopy) products
-

Chapter 2. The C-CAP Coastal Land Cover Classification System

It is essential that the coastal land cover information stored in the C-CAP database be taxonomically correct and consistent with coastal wetland information derived from other agencies. The C-CAP Coastal Land Cover Classification System (Table 2) includes three Level I super classes (Klemas et al. 1993):

- 1.0 Upland
- 2.0 Wetland

- 3.0 Water and Submerged Land.

These super classes are subdivided into classes and subclasses at Levels II and III, respectively. While the latter two categories constitute the primary habitats of interest to NOAA, uplands are also included because they influence adjacent wetlands and water bodies. The classification system is hierarchical, reflects ecological relationships, and focuses on land cover classes that can be discriminated primarily from satellite remote sensor data. It was adapted and designed to be compatible with other nationally standardized classification systems, especially:

- The U.S. Geological Survey's "Land Use/Land Cover Classification System For Use with Remote Sensor Data" (Anderson et al. 1976; USGS 1992; [Appendix 1](#) - Table A1)
- The U.S. Fish and Wildlife Service's "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin et al. 1979; Wilen 1990; [Appendix 2](#) - Table A2)
- The Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) classification system.

Dedicated workshops on the C-CAP Classification System and productive discussions and reviews with representatives from each of these major agencies resulted in a classification system which is in harmony with other major United States land cover databases. The C-CAP Coastal Land Cover Classification System includes upland, wetland, submerged land, and water in a single, comprehensive scheme. An attempt has been made to identify land cover classes that can be derived primarily through remotely sensing and that are important indicators of ecosystem change. Modifications were necessary to reconcile inconsistencies between Anderson et al. (1976) and Cowardin et al. (1979), and remove all land use categories (Dobson 1993a). C-CAP focuses on land cover and its relationship to other functional components of landscape (Dobson 1993b). Definitions of the pertinent terms are:

- Land cover- vegetation, soils, rocks, water (in its various forms) and constructed materials covering the land surface, physically present and visible.
- Land use - economic and cultural activities permitted and/or practiced at a place which may or may not be manifested as visible land cover features. For example, forestry land use may be visibly manifested as forest land cover, but recreational land use may occur in many different types of land cover, often without visible evidence of recreational use.
- landscape -the zone of interaction and convergence of the atmosphere, the hydrosphere, and the solid earth. Its vertical bounds are determined by the frequency and extent of interactions pertinent to a given field of inquiry. Horizontally, landscape may be divided into areal units defined on the basis of physical or cultural features pertinent to a field of inquiry.

While all categories of the C-CAP classification system can be represented as two-dimensional features at the mapping scale of 1:24,000, some features may be mapped as lines (e.g., a Marine/Estuarine Rocky Shore) or points (e.g., unique landmarks). Most linear and point features will be obtained from non-satellite sources of information (e.g. aerial photography or in situ measurement using global positioning systems). Those classes and subclasses which are required by C-CAP and which each regional C-CAP project will include in its database are underlined in Table 1. The underlined classes, with the exception of aquatic beds, can generally be detected by satellite remote sensors, particularly when supported by surface in situ measurement.

Super Classes of the C-CAP Coastal Land Cover Classification System

Uplands

The Uplands super class consists of seven subclasses (**Table 2.**): Developed Land, Cultivated Land, Grassland, Woody Land, Bare Land, Tundra and Snow/Ice. Upland classes are adapted from Level I classes in the USGS Land Use/Land Cover Classification System (Anderson et al. 1976; USGS 1992; Appendix 1 - Table A1). Detailed definitions of all C-CAP classes and subclasses in Table 1 are found in [Appendix 3](#).

Table 2. C-CAP Coastal Land Cover Classification System (Modified from Klemas et al., 1993)

1.0 Upland

1.1 Developed Land

1.11 High Intensity

1.12 Low Intensity

1.2 Cultivated Land

1.21 Orchards/Groves/Nurseries

1.22 Vines/Bushes

1.23 Cropland

1.3 Grassland

1.31 Unmanaged

1.32 Managed

1.4 Woody Land

1.41 Deciduous

1.411 Forest

1.412 Scrub/Shrub

1.42 Evergreen

1.421 Forest

1.422 Scrub/Shrub

1.43 Mixed

1.431 Forest

1.432 Scrub/Shrub

1.5 Bare Land

1.6 Tundra

1.7 Snow/Ice

1.71 Perennial Snow/Ice

1.72 Glaciers

2.0 Wetland (Excludes Bottoms, Reefs, Nonpersistent Emergent Wetlands, and Aquatic Beds, all of which are covered under 3.0, Water and Submerged Land.)

2.1 Marine/Estuarine Rocky Shore

2.11 Bedrock

2.12 Rubble

2.2 Marine/Estuarine Unconsolidated Shore (Beach, Flat, Bar)

2.21 Cobble-gravel

2.22 Sand

2.23 Mud/Organic

2.3 Estuarine Emergent Wetland

2.31 Haline (Salt Marsh)

2.32 Mixohaline (Brackish Marsh)

2.4 Estuarine Woody Wetland

2.41 Deciduous

2.411 Forest

2.412 Scrub/Shrub

2.413 Dead

2.42 Evergreen

2.421 Forest

2.422 Scrub/Shrub

2.423 Dead

2.43 Mixed

2.431 Forest

2.432 Scrub/Shrub

2.433 Dead

2.5 Riverine Unconsolidated Shore (Beach, Flat, Bar)

2.51 Cobble-gravel

2.52 Sand

2.53 Mud/Organic

2.6 Lacustrine Unconsolidated Shore (Beach, Flat, Bar)

2.61 Cobble-gravel

2.62 Sand

2.63 Mud/Organic

2.7 Palustrine Unconsolidated Shore (Beach, Flat, Bar)

2.71 Cobble-gravel

2.72 Sand

2.73 Mud/Organic

2.8 Palustrine Emergent Wetland (Persistent)

2.9 Palustrine Woody Wetland

2.91 Deciduous

2.911 Forest

2.912 Scrub/Shrub

2.913 Dead

2.92 Evergreen

2.921 Forest

2.922 Scrub/Shrub

2.923 Dead

2.93 Mixed

2.931 Forest

2.932 Scrub/Shrub

2.933 Dead

3.0 Water and Submerged Land (Includes deepwater habitats and those wetlands with surface water but lacking trees, shrubs, and persistent emergents)

3.1 Water (Bottoms and undetectable reefs, aquatic beds or nonpersistent emergent Wetlands)

3.11 Marine/Estuarine

3.12 Riverine

3.13 Lacustrine (Basin > 20 acres)

3.14 Palustrine (Basin < 20 acres)

3.2 Marine/Estuarine Reef

3.3 Marine/Estuarine Aquatic Bed

3.31 Algal (e.g., kelp)

3.32 Rooted Vascular (e.g., seagrass)

3.321 High Salinity (> 5 ppt; Mesohaline, Polyhaline, Euhaline, Hyperhaline)

3.322 Low Salinity (< 5 ppt; Oligohaline, Fresh)

3.4 Riverine Aquatic Bed

3.41 Rooted Vascular/Algal/Aquatic Moss

3.42 Floating Vascular

3.5 Lacustrine Aquatic Bed (Basin > 20 acres)

3.51 Rooted Vascular/Algal/Aquatic Moss

3.52 Floating Vascular

3.6 Palustrine Aquatic Bed (Basin < 20 acres)

3.61 Rooted Vascular/Algal/Aquatic Moss

3.62 Floating Vascular

Developed Land (Derived from the Anderson et al. [1976] Urban or Built-up class) characterizes constructed surfaces comprised of concrete, asphalt, roofing, and other building materials with or without vegetation. This class has been divided into two subclasses based on the amount of constructed surface relative to the amount of vegetated surface present. High Intensity Developed Land contains little or no vegetation. This subclass includes heavily built-up urban centers as well as large constructed surfaces in suburban and rural areas. Large buildings (such as multiple family housing, hangars, and large barns), interstate highways, and runways typically fall into this subclass. Low Intensity Developed Land contains substantial amounts of constructed surface mixed with substantial amounts of vegetated surface. Small buildings (such as single family housing, farm outbuildings, and sheds), streets, roads, and cemeteries with associated grasses and trees typically fall into this subclass.

Cultivated Land (Agricultural Land in Anderson et al. 1976) includes herbaceous (cropland) and woody (orchards, nurseries, vineyards, etc.) cultivated lands. Seasonal spectral signatures, geometric field patterns and road network patterns may help identify this land cover type. Always associated with agricultural land use, cultivated land is used for the production of food and fiber.

Grassland differs from Rangeland in Anderson et al. (1976) by excluding shrub-brushlands. Unmanaged Grasslands are dominated by naturally occurring grasses and forbs which are not fertilized, cut, tilled or planted regularly. Managed Grasslands are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Examples of such areas include lawns, golf courses, forest or shrub areas converted to grassland, or areas of permanent grassland with altered species composition. This category includes managed pastures and pastures with vegetation that grows vigorously as fallow. Managed Grasslands are used for grazing or for growing and harvesting hay and straw for animal feed.

Woody Land includes non-agricultural trees and shrubs. The category alleviates the problem of separating various sizes of trees and shrubs using satellite remote sensor data but allows a height-based separation if high resolution aerial photography are available. The class may be partitioned into three subclasses: Deciduous, Evergreen, and Mixed. These three subclasses generally can be discriminated with satellite remote sensing systems.

Bare Land (derived from Barren Land in Anderson et al. 1976) is composed of bare soil, rock, sand, silt, gravel, or other earthen material with little or no vegetation. Anderson's Barren Land was defined as having limited ability to support life; C-CAP's Bare Land is defined by the absence of vegetation without regard to inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the vegetated classes. Unusual conditions such as a heavy rainfall may occasionally result in growth of a short-lived, luxuriant plant cover. Wet, nonvegetated exposed lands are included in the Wetland categories. Bare Land may be bare temporarily because of human activities. The transition from Woody Land, Grassland, or Cultivated Land to Developed Land, for example, usually involves a Bare Land phase. Developed Land also may have temporary waste and tailing piles. Woody Land may be clearcut producing a temporary Bare Land phase. When it may be inferred from the data that the lack of vegetation is due to an annual cycle of cultivation (eg. plowing), the land is not included in the Bare Land class. Land temporarily without vegetative cover because of cropping or tillage, is classified as Cultivated Land, not Bare Land.

Wetlands

Wetlands are lands where saturation with water is the dominant factor determining soil development and

the types of plant and animal communities living in the soil and on its surface (Cowardin et al. 1979). A characteristic feature shared by all wetlands is soil or substrate that is at least periodically saturated with or covered by water. The upland limit of wetlands is designated as (1) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover; (2) the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric; or (3) in the case of wetlands without vegetation or soil, the boundary between land that is flooded or saturated at some time during the growing season each year and land that is not (Cowardin et al. 1979). The majority of all wetlands are vegetated and are found on soil.

Wetland in the C-CAP Coastal Land Cover Classification System (Table 1) includes all areas considered wetland by Cowardin et al. (1979) except for bottoms, reefs, aquatic beds, and Nonpersistent Emergent Wetlands. The class subdivision was adopted primarily from the Cowardin system, shown in [Appendix 2](#) (Table A2). At Level II, C-CAP incorporates certain Cowardin classes (e.g., Rocky Shore, Unconsolidated Shore, Emergent Wetland) or grouped Cowardin classes (e.g., Woody Wetland may be further divided into Scrub-Shrub and Forested categories), in combination with Cowardin systems (i.e., Marine, Estuarine, Riverine, Lacustrine, Palustrine). Thus, a typical Level II class in the C-CAP system might be Palustrine Woody Wetland.

Marine and Estuarine Rocky Shores (Cowardin et al. 1979) were combined into a single class, Marine/Estuarine Rocky Shore. The same logic was used to produce Marine/Estuarine Unconsolidated Shore.

Salinity exhibits a horizontal gradient in coastal estuary marshes. This is evident not only through the direct measurement of salinity but in the horizontal distribution of marsh plants (Daiber 1986). Therefore, the Estuarine Emergent Wetland class is partitioned into Haline (Salt) and Mixohaline (Brackish) Marshes. For both subclasses, the C-CAP Classification System uses the Cowardin et al. (1979) definitions. Mixohaline salinity ranges from 0.5 ppt to 30 ppt, and Haline salinity is >30 ppt. Within a marsh, plant zonation is usually quite evident. Along the Atlantic coast of North America the pioneer plant on regularly flooded mudflats is saltmarsh cordgrass, *Spartina alterniflora*, which often appears in pure stands. In more elevated areas which are flooded less frequently saltmeadow hay, *Spartina patens* often dominates. The upland interfaces are bordered by marsh elder, *Iva frutescens* and groundsel tree, *Baccharis halimifolia*. Thus, salt marshes may be subdivided further into High Marsh and Low Marsh, but this distinction is not required in C-CAP regional projects.

The C-CAP Coastal Land Cover Classification System does not attempt to identify freshwater Nonpersistent Emergent Wetlands because they are invisible during much of the year and difficult to detect by remote sensors. These wetlands are classified as "Riverine Water" and "Lacustrine Water," respectively.

Water and Submerged Land

All areas of open water with < 30% cover of trees, shrubs, persistent emergent plants, emergent mosses, or lichens are assigned to Water and Submerged Land, regardless of whether the area is considered wetland or deepwater habitat under the Cowardin et al. (1979) classification.

The Water class includes Cowardin et al.'s (1979) Rock Bottom and Unconsolidated Bottom, and Nonpersistent Emergent Wetlands, as well as Reefs and Aquatic Beds that are not identified as such. Most C-CAP products will display water as a single class. However, it is recognized that the major systems (Marine/Estuarine, Riverine, Lacustrine, Palustrine) are ecologically different from one another.

For this reason, the C-CAP system identifies the four systems as Level III subclasses, i.e., 3.11 Marine/Estuarine Water, 3.12 Riverine Water, 3.13 Lacustrine Water, and 3.14 Palustrine Water. While C-CAP does not require these subclasses, the option is provided to participants who may have such data available from ancillary sources. Having the water subclasses also makes the C-CAP scheme more compatible with the Cowardin et al. (1979) system. The subclass 3.11 Marine/Estuarine Water includes Bottoms and undetected Reefs and Aquatic Beds. The subclasses 3.12 Riverine Water, 3.13 Lacustrine Water, and 3.14 Palustrine Water include Bottoms and undetected Aquatic Beds as well as Nonpersistent Emergent Wetlands. Palustrine waterbodies, defined as covering < 20 acres, are smaller than Lacustrine waterbodies.

C-CAP combined Marine and Estuarine Reefs and Aquatic Beds into two classes, Marine/Estuarine Reefs and Marine/Estuarine Aquatic Beds. Marine/Estuarine Aquatic Beds includes the subclass Rooted Vascular which is subdivided into High Salinity (> 5 ppt) and Low Salinity (< 5 ppt). The >5 ppt salinity separates seagrasses from low salinity tolerating or requiring submersed grasses and forbs. Both types of plants define aquatic beds, submersed habitats, which are important to the C-CAP project. High Salinity includes mesohaline, polyhaline, euhaline, and hyperhaline salinity categories of Cowardin et al. (1979). Low Salinity includes oligohaline and fresh categories (< 5 ppt salinity).

With the noted exceptions, most of the Wetland and Water classes have definitions similar to those contained in Cowardin et al. (1979) so that data can be interchanged with other programs, such as the U.S. Fish and Wildlife Service, National Wetlands Inventory (NWI) program, which is based on the Cowardin et al. (1979) classification system. Detailed definitions of all super classes, classes and subclasses shown in Table 1 are provided in [Appendix 3](#).

Chapter 3. Guidelines for Monitoring Uplands and Wetlands Using Satellite Remote Sensor Data

Successful remote sensing change detection of uplands and wetlands in coastal regions requires careful attention to: 1) sensor systems; 2) environmental characteristics; and 3) geodetic control. Failure to understand the impact of the various parameters on the change detection process can lead to inaccurate results. Ideally, the remotely sensed data used to perform C-CAP change detection are acquired by a remote sensor system which holds the following factors constant: temporal, spatial (and look angle), spectral, and radiometric. It is instructive to review each of these parameters and identify why they have a significant impact on the success of C-CAP remote sensing change detection projects. **Table 3.** summarizes the characteristics of some of the most important satellite remote sensing systems.

Table 3. Selected Satellite Remote Sensing System Characteristics

Format Type	Spectral Resolution(mm)	Spatial Resolution(m)	Temporal Resolution	Radiometric Resolution
Landsat MS	Band 1 (.50 - .60)	80 x 80	18 days	8 bits
Landsat MS	Band 2 (.60 - .70)	80 x 80	18 days	8 bits

Landsat MS	Band 3 (.70 - .80)	80 x 80	18 days	8 bits
Landsat MS	Band 4 (.80 - 1.1)	80 x 80	18 days	8 bits
Landsat Thematic Mapper 4 & 5	Band 1 (.45 - .52)	80 x 80	18 days	8 bits
Landsat Thematic Mapper 4 & 5	Band 2 (.52 - .60)	30 x 30	16 days	8 bits
Landsat Thematic Mapper 4 & 5	Band 3 (.63 - .69)	80 x 80	18 days	8 bits
Landsat Thematic Mapper 4 & 5	Band 4 (.76 - .90)	30 x 30	16 days	8 bits
Landsat Thematic Mapper 4 & 5	Band 5 (1.55 - 1.75)	30 x 30	16 days	8 bits
Landsat Thematic Mapper 4 & 5	Band 7 (2.08 - 2.35)	30 x 30	16 days	8 bits
Landsat Thematic Mapper 4 & 5	Band 6 (10.4 - 12.5)	120 x 120	16 days	8 bits
SPOT HRV XS	Band 1 (.50 - .59)	20 x 20	pointable	8 bits
SPOT HRV XS	Band 2 (.61 - .68)	20 x 20	pointable	8 bits
SPOT HRV XS	Band 3 (.79 - .89)	20 x 20	pointable	8 bits
SPOT HRV XS	Pan(.51 - .73)	10 x 10	pointable	8 bits

¹ Landsat MSS 1 and 2 collected data in 7 bits.

Remote Sensing System Considerations

Temporal Resolution

There are two important temporal resolutions which should be held constant when performing coastal change detection using multiple dates of remotely sensed data. First, the data should be obtained from a sensor system which acquires data at approximately the same time of day (e.g., Landsat Thematic Mapper data are acquired before 9:45 am for most of the conterminous United States). This eliminates diurnal sun angle effects which can cause anomalous differences in the reflectance properties of the remotely sensed data. Second, whenever possible it is desirable to use remotely sensed data acquired on anniversary dates, e.g., October 1, 1988 versus October 1, 1993. Using anniversary date imagery removes seasonal sun angle differences which can make change detection difficult and unreliable (Jensen et al. 1993a). Usually precise anniversary date imagery is not available. The determination of acceptable near-anniversary dates then depends on local and regional factors such as phenological cycles and annual climatic regimes.

Spatial Resolution and Look Angle

Accurate spatial registration of at least two images is essential for digital change detection. Ideally, the remotely sensed data are acquired by a sensor system which collects data with the same instantaneous-field-of-view (IFOV) on each date. For example, Landsat Thematic Mapper data collected at 30 x 30 m spatial resolution (Table 3) on two dates are relatively easy to register to one another. Geometric rectification algorithms (Jensen 1986; Novak 1992) are used to register the images to a standard map projection (Universal Transverse Mercator - UTM, for most U.S. projects). Rectification should result in the two images having a root mean square error (RMSE) of $< +0.5$ pixel. $RMSE > +0.5$ pixel may result in the identification of spurious areas of change between the two data sets. See ["Rectification of Multiple-Date Remote Sensor Data to Detect Change"](#) for a summary of C-CAP image rectification requirements.

It is possible to perform change detection using data collected by two different sensor systems with different IFOVs, e.g. Landsat TM data (30 x 30 m) for date 1 and SPOT HRV data (20 x 20 m) for date 2. In such cases, it is necessary to decide upon a representative minimum mapping unit (e.g. 20 x 20 m) and then resample both data sets to this uniform pixel size. This does not present a significant problem as long as one remembers that the information content of the resampled data can never be greater than the IFOV of the original sensor system (i.e. even though the Landsat TM data are resampled to 20 x 20 m pixels, the information was still acquired at 30 x 30 m resolution and one should not expect to be able to extract additional spatial detail in the dataset).

Some remote sensing systems like SPOT collect data at off-nadir look angles as much as $+20^\circ$ (Table 23, i.e. the sensors obtain data of an area on the ground from an "oblique" vantage point. Two images with significantly different look angles can cause problems when used for change detection purposes. For example, consider a maple forest consisting of very large, randomly spaced trees. A SPOT image acquired at 0° off-nadir will look directly down upon the "top" of the canopy. Conversely, a SPOT image acquired at 20° off-nadir will record reflectance information from the "side" of the canopy. Differences in reflectance from the two datasets can cause spurious change detection results. Therefore, the data used in a remote sensing digital change detection should be acquired with approximately the same look angle whenever possible.

Spectral Resolution

A fundamental assumption of digital change detection is that there should exist a difference in the spectral response of a pixel on two dates if the biophysical materials within the IFOV have changed between dates. Ideally, the spectral resolution of the remote sensor system is sufficient to record reflected radiant flux in spectral regions that best capture the most descriptive spectral attributes of the object.

Unfortunately, different sensor systems do not record energy in exactly the same portions of the electromagnetic spectrum, i.e. bandwidths (Table 3). For example, Landsat MSS records energy in four relatively broad bands, SPOT HRV sensors record in three relatively coarse multispectral bands and one panchromatic band, and TM in six relatively narrow optical bands and one broad thermal band (Table 3). Ideally, the same sensor system is used to acquire imagery on multiple dates. When this is not possible, the analyst should select bands which approximate one another. For example, SPOT bands 1 (green), 2 (red), and 3 (near-infrared) can be used successfully with TM bands 2 (green), 3 (red), and 4 (near-infrared) or MSS bands 1 (green), 2 (red), and 4 (near-infrared). Many of the change detection algorithms to be discussed do not function well when bands from one sensor system do not match those of another sensor system, e.g. utilizing TM band 1 (blue) with either SPOT or MSS data is not wise.

Radiometric Resolution

An analog to digital conversion of the satellite remote sensor data usually results in 8-bit brightness values with values ranging from 0 to 255 (Table 3). Ideally, the sensor systems collect the data at the same radiometric precision on both dates. When the radiometric resolution of data acquired by one system (e.g., MSS 1 with 7-bit data) are compared with data acquired by a higher radiometric resolution instrument (e.g., TM with 8-bit data) then the lower resolution data (e.g., 7-bit) should be "decompressed" to 8-bits for change detection purposes. However, the precision of decompressed brightness values can never be better than the original, uncompressed data.

The Preferred C-CAP Satellite Sensor System

TM is currently the primary sensor recommended for C-CAP image acquisition and change analysis for all land cover except aquatic beds. A TM image, although its spatial resolution is not as good as that of a SPOT satellite or aircraft MSS image, is generally less expensive to acquire and process for large-area coverage. Compared to SPOT imagery, TM has better spectral resolution and specific spectral bands that are more applicable to wetlands delineation (bands 5 and 7). In addition, TM is preferred over SPOT because TM has collected data for a longer time (since 1982 as opposed to SPOT since 1986) and because many TM scenes of the United States coastal regions were systematically collected on a routine basis.

There are advantages and disadvantages to using other sensors. Aircraft multispectral scanners are more expensive and complex to utilize over large regions (Jensen et al. 1987). However, good algorithms are now available for georeferencing, and in certain cases (e.g., when higher spectral or spatial resolution is needed and when unfavorable climactic conditions for satellite sensors exist) aircraft sensors may be optimum. The SPOT sensor has a greater temporal coverage because the satellite can collect data off-nadir. However, if off-nadir SPOT imagery is used for C-CAP change analyses, the data must be normalized to compensate for different look angles that may preclude pixel-to-pixel spectral-change analysis. Nevertheless, SPOT imagery may be a reasonable alternative in certain areas due to cloud cover or other impediments to TM data availability.

C-CAP remains flexible in order to take advantage of new sensors and other technologies that become operational during the lifetime of the program. Regional participants should work with the C-CAP

program coordinators to ensure that the sensor selection meets the following C-CAP requirements.

- Standard radiometrically corrected TM data are required, and geocoded (georeferenced) data are optional. If geocoded data are selected, the coordinate system should be Universal Transverse Mercator (UTM).
- Regional participants must collaborate with C-CAP managers to ensure that the exchange medium and its format will be amenable to the processing capabilities of the participants.
- C-CAP normally will purchase and archive the raw data in collaboration with the regional image processing center. In cases where the regional participants already have usable raw imagery or are making their own purchases, formal agreements between C-CAP managers and the participant must address vendor licensing and other legal requirements as well as C-CAP archiving and quality-control protocol.

Environmental Characteristics of Importance When Performing Change Detection

Failure to understand the impact of various environmental characteristics on the remote sensing change detection process can also lead to inaccurate C-CAP results. When performing change detection it is desirable to hold environmental variables as constant as possible. Specific environmental variables and their potential impacts are described below.

Atmospheric Conditions

There should be no clouds, haze, or extreme humidity on the days remote sensing data are collected. Even a thin layer of haze can alter spectral signatures in satellite images enough to create the false impression of spectral change between two dates. Obviously, 0% cloud cover is preferred for satellite imagery and aerial photography. At the upper limit, cloud cover > 20% is usually unacceptable. It should also be remembered that clouds not only obscure terrain but the cloud shadow also causes major image classification problems. Any area obscured by clouds or affected by cloud shadow will filter through the entire change detection process, severely limiting the utility of the final change detection product. Therefore, regional analysts must use good professional judgment in evaluating such factors as the criticality of the specific locations affected by cloud cover and shadow, and the availability of timely surrogate data for those areas obscured (e.g. perhaps substituting aerial photography interpretation for a critical area). Even when the stated cloud cover is 0%, it is advisable to "browse" the proposed image on microfiche at the National Cartographic Information Center in each state to confirm that the cloud cover estimate is correct.

Assuming no cloud cover, the use of anniversary dates helps to ensure general, seasonal agreement between the atmospheric conditions on the two dates. However, if dramatic differences exist in the atmospheric conditions present on the n dates of imagery to be used in the change detection process, it may be necessary to remove the atmospheric attenuation in the imagery. Two alternatives are available. First, sophisticated atmospheric transmission models can be used to correct the remote sensor data if substantial in situ data are available on the day of the overflights. Second, an alternative empirical method may be used to remove atmospheric effects. A detailed description of one empirical method of image to image normalization is found in ["Radiometric Normalization of Multi-date Images to Detect Change"](#).

Soil Moisture Conditions

Ideally, the soil moisture conditions should be identical for the n dates of imagery used in a change detection project. Extremely wet or dry conditions on one of the dates can cause serious change detection problems. Therefore, when selecting the remotely sensed data to be used for change detection it is very important not only to look for anniversary dates, but also to review precipitation records to determine how much rain or snow fell in the days and weeks prior to remote sensing data collection. When soil moisture differences between dates are significant for only certain parts of the study area (perhaps due to a local thunderstorm), it may be necessary to stratify (cut-out) those affected areas and perform a separate analysis which can be added back in the final stages of the project.

Vegetation Phenological Cycle Characteristics

Vegetation grows according to seasonal and annual phenological cycles. Obtaining near-anniversary images greatly minimizes the effects of wetland seasonal phenological differences which may cause spurious change to be detected in the imagery. One must also be careful about two other factors when dealing with man-made upland seasonal agricultural crops. First, many monoculture crops (e.g. corn) normally are planted at approximately the same time of year. A month lag in planting date between fields having the same crop can cause serious change detection error. Second, many monoculture crops are comprised of different species (or strains) of the same crop which can cause the crop to reflect energy differently on multiple dates of anniversary imagery. These observations suggest that the analyst must know the biophysical characteristics of the vegetation as well as the cultural land-tenure practices in the study area so that imagery which meets most of these characteristics can be selected for change detection.

The choice of image date is best determined by mutual agreement among remote sensing specialists, biologists, ecologists, and local experts. The selection of the acceptable window of acquisition will be made independently by participants in each region. No single season will serve for all areas because of substantial latitudinal variation extending from temperate to tropical regions. For example, coastal marshes in the Mid Atlantic Region are best inventoried from June through October while submersed habitats in southern Florida may be inventoried best in November. Even within regions, some cover types will be more easily distinguished in different seasons. For example, in the Caribbean, estuarine seagrasses can be detected best in early January, yet marine seagrasses can be detected best in May or June. Technically, these vegetation patterns should be monitored at optimal times throughout the year, but cost limitations usually limit the analyst to a single date.

Effects of Tidal Stage on Image Classification

Tide stage is a crucial factor in satellite image scene selection and the timing of aerial surveys. Ideally, tides should be constant between time periods, but this would rule out synoptic satellite sensors since tide stages are not synchronized within a region or even within a single image. Alternatively, analysts should avoid selecting the highest tides and should take into account the tide stages occurring throughout each scene. Tidal effect varies greatly among regions. In the Northwest, for example, when all of the temporal, atmospheric, and tidal criteria are taken into account the number of acceptable scenes may be quite small. In some regions it may be necessary to seek alternative data such as SPOT satellite data, aerial photographs, or other land cover databases. For most regions, mean low tide (MLT) or lower will be preferred, one or two feet above MLT will be acceptable, and three feet or more will be unacceptable (Jensen et al. 1993a). Ideally, tides for aerial photographic surveys of submersed habitat should approach low tide as predicted in NOAA, National Ocean Service (NOS) tide tables, but optimal visualization of the subtidal bottom depends on water clarity as well as depth. Two of the 1993 C-CAP protocol

development projects focus on improving the C-CAP protocol for tidal effects (See [Appendix 5](#)).

Image Processing of Satellite Remote Sensing Data to Inventory Upland and Wetland Change

With the Classification scheme developed and the appropriate remote sensor data selected, it is possible to process the data to extract upland and wetland change information. This involves geometric and radiometric correction, selection of an appropriate change detection algorithm, classification if necessary, creation of change detection products, and error evaluation (Figure 1). A separate section (Chapter 4) describes the extraction of information on SRV because aerial photography and significantly different photogrammetric techniques must be utilized.

Rectification of Multiple-Date Remote Sensor Data to Detect Change

Georeferencing (spatial registration of a remotely sensed image to a standard map projection) is a necessary step in digital change detection and cartographic representation. The following C-CAP recommendations should be followed when rectifying the base image to a standard basemap:

- Geocoded base TM images can be purchased if preferred by regional analysts. However, participants should be aware that some analysts have reported undocumented variations in commercial products that can lead to poor registration in certain regions, especially where local relief requires substantial terrain correction. Additional registration may be necessary to achieve the C-CAP standard precision of RMSE +0.5 pixel. Therefore, it is recommended that each regional project perform its own base image to map rectification using the radiometrically corrected but not geocoded data.
- Ground control points (GCPs) used to compute rectification transformation coefficients should be relatively static features in the landscape (e.g. road intersections) or based on new Global Positioning System (GPS) measurements taken in the field. When GCPs are digitized from USGS 7.5' (1:24,000) maps, analysts should use the marginal information and updates available to improve location of the control points. GCPs should be extracted from mylar copies of the USGS maps whenever possible to minimize system produced digitizing error. Traditional paper maps expand and contract with changes in relative humidity and should not be used for digitizing GCPs.
- C-CAP recommends the use of the current NAD '83 national datum. Unfortunately, most existing map series are based on the NAD '27 datum. NAD '27 will be acceptable on a region by region basis until published maps based on NAD '83 are universally available.
- In all but the flattest coastal regions, terrain correction of imagery may be necessary to reduce image distortion caused by local relief. The required coordinate system is Universal Transverse Mercator (UTM). If another coordinate system is used (e.g. state plane), it is the responsibility of the regional analyst to provide complete documentation and conversion equations.
- It is the responsibility of the regional analyst to understand (or seek advice concerning) the variety of rectification resampling algorithms (e.g., bilinear interpolation, nearest neighbor, cubic convolution) and their impact on the data. Nearest neighbor resampling is recommended.

Rectification of an earlier date (Tb-1) or later date (Tb+1) to the base image (Tb) can be accomplished in several ways. The primary concern is to accomplish the most exact co-registration of pixels from each time period and thus reduce a potentially significant source of error in change analysis (Lunetta et al. 1991). The following are minimum recommendations and requirements:

- Geocoded and terrain-corrected TM data can be ordered from commercial vendors. Two separate images can be overlaid according to like coordinates, but this technique may introduce error if prior geocoding was not precisely the same in both images. The regional analyst has no control in this process, but if high precision is accomplished by the vendor, the analyst can significantly reduce image processing effort at the regional facility. The regional analyst can geocode the image to UTM coordinates as was done with the base image. If this technique is adopted, it is important to use the identical GCPs and resampling algorithm used to rectify the base image.
- For multiple images, the preferred technique is to rectify non-geocoded images directly to the geocoded base image. This technique may have the advantage of reducing or better controlling co-registration error among images. Selection and consistency of control points and rectification algorithms are important to the success of this technique. Cubic convolution algorithms normally yield the most precise spatial fit, but cubic convolution and bilinear interpolation algorithms suffer from the disadvantage of averaging pixel brightness values. Nearest neighbor algorithms are spatially less precise, but they offer the advantage of retaining pixel brightness values through the processes of rectification and registration.

Radiometric Normalization of Multi-Date Images to Detect Change

The use of remotely sensed data to classify coastal and upland land cover on individual dates is contingent upon there being a robust relationship between remotely sensing brightness values (BVs) and actual surface conditions. However, factors such as sun angle, Earth/sun distance, detector calibration differences between the various sensor systems, atmospheric condition, and sun/target/sensor geometry (phase angle) will also affect pixel brightness value. Differences in direct beam solar radiation due to variation in sun angle and Earth/sun distance can be calculated accurately, as can variation in pixel Bvs due to detector calibration differences between sensor systems. Removal of atmospheric and phase angle effects require information about the gaseous and aerosol composition of the atmosphere and the bi-directional reflectance characteristics of elements within the scene. However, atmospheric and bi-directional reflectance information are rarely available for historical remotely sensed data. Also, some analysts may not have the necessary expertise to perform a theoretically based atmospheric path radiance correction on remotely sensed data. Hence, it is suggested that a relatively straightforward "empirical scene normalization" be employed to match the detector calibration, astronomic, atmospheric, and phase angle conditions present in a reference scene.

Image normalization reduces pixel BV variation caused by non-surface factors so variations in pixel BVs between dates can be related to actual changes in surface conditions. Normalization enables the use of image analysis logic developed for a base year scene to be applied to the other scenes. This can be accomplished using techniques pioneered by personnel of the U.S. Bureau of Land Management (Eckhardt et al. 1990). Image normalization is achieved by developing simple regression equations between the brightness values of "normalization targets" present in Tb and the scene to be normalized (e.g. Tb-1 or Tb+1). Normalization targets are assumed to be constant reflectors, therefore any changes in their brightness values are attributed to detector calibration, astronomic, atmospheric, and phase angle differences. Once these variations are removed, changes in BV may be related to changes in surface conditions.

Acceptance criteria for potential "normalization targets" are (Eckhardt et al 1990):

- The targets must be at approximately the same elevation as the land cover of primary interest within the scene. Most aerosols in the atmosphere occur < 1000 m above ground level (AGL).

Selecting a mountain top normalization target, thus, would be of little use in estimating atmospheric conditions near sea level. Although C-CAP projects are on the coast, many regions include areas of substantial local relief.

- The targets should contain only minimal amounts of vegetation. Vegetation spectral reflectance can change over time due to environmental stresses and plant phenology. Good targets include bare soil fields and deep, non-turbid water bodies.
- The targets must be on relatively flat terrain so that incremental changes in sun angle between dates will have the same proportional increase or decrease in direct beam sunlight for all normalization targets.
- The normalization targets should have approximately the same texture over time. Changing textural patterns indicate variability within the target which could mean that the reflectance of the target as a whole may not be constant over time. For example, a mottled pattern on what had previously been a uniformly gray dry lake bed indicates changing surface moisture conditions, which would eliminate the dry lake bed from consideration as a normalization target.

The mean BVs of the T_b targets are regressed against the mean BVs of the T_{b-1} or T_{b+1} targets for the n bands used in the classification of the remote sensor data (e.g. TM bands 2, 3, and 4). The slope and y-intercept of the n equations are then used to normalize the Time 2 Landsat TM data to the Time 1 Landsat TM data. Each regression model contains an additive component (y- intercept) that corrects for the difference in atmospheric path radiance between dates, and a multiplicative term (slope) that corrects for the difference in detector calibration, sun angle, Earth/sun distance, atmospheric attenuation, and phase angle between dates.

It is customary to first normalize the remote sensor data and then perform image rectification (using nearest-neighbor resampling if image classification is to take place). These data are then ready for individual date classification or the application of various multi-image change detection algorithms. Most studies that attempt to monitor biophysical properties such as vegetation biomass, chlorophyll absorption, health, and other biophysical properties require atmospheric correction.

Selecting the Appropriate Change Detection Algorithm

C-CAP is the first federal program to state as a primary goal the monitoring of coastal habitat change using satellite technology (Cross and Thomas 1992). The implementation and continuing evolution of the program is based on the fact that improved cartographic, digital image processing, and photointerpretation methods must be developed for a program of this geographic coverage, spatial resolution, and temporal frequency (nationwide, 30 x 30 m pixel, every one to five years). Initial implementation of C-CAP will require a blend of traditional and innovative approaches to change analysis. The fact that the program has adopted a digital format, with the TM as a primary sensor, means that new techniques in processing can be easily incorporated into future iterations.

The selection of an appropriate change detection algorithm is very important (Jensen 1986; Dobson and Bright 1991, 1992, 1993; Jensen et al. 1993a). First, it will have a direct impact on the type of image classification to be performed (if any). Second, it will dictate whether important "from-to" information can be extracted from the imagery. C-CAP requires that the "from-to" information be readily available in digital form suitable for geographic analysis and for producing maps and tabular summaries. At least seven change detection algorithms are commonly used by the remote sensing community, including:

- Change Detection Using Write Function Memory Insertion

- Example: Kittredge and Fort Moultrie, SC
- Multi-date Composite Image Change Detection
 - No example provided
- Image Algebra Change Detection (Band Differencing or Band Ratioing)
 - No example provided
- Post-classification Comparison Change Detection
 - Example: Fort Moultrie, SC
- Multi-date Change Detection Using A Binary Mask Applied to Tb-1
 - Example: Chesapeake Bay, MD
- Multi-date Change Detection Using Ancillary Data Source as Tb
 - No example provided
- Manual, On-screen Digitization of Change
 - No example provided

It is instructive to review these alternatives, identify those acceptable to C- CAP, and provide specific examples where appropriate.

Change Detection Using Write Function Memory Insertion

It is possible to insert individual bands of remotely sensed data into specific write function memory banks (red, green, and/or blue) in the digital image processing system (**Figures 1. & 2.**) to visually identify change in the imagery (Jensen et al. 1993b). For example, consider two Landsat Thematic Mapper scenes of the Fort Moultrie quadrangle near Charleston, SC obtained on November 11, 1982 and December 19, 1988. Band 1 of the 1982 image was placed in the green image plane and band 1 of the 1988 image in the red image plane and no image in the blue image plane (**Figure 3.**). All areas which did not change between the two dates are depicted in shades of yellow (i.e. in additive color theory, equal intensities of green and red make yellow). The graphic depicts numerous changes, including:

- beach and sand bar accretion (red) and erosion (green)
- new urban development (red)
- changes in tidal stage between dates (green and red)

Multi-Date Visual Change Detection Using Write-Function Memory Insertion

**Advantages:**

- visual examination of 2 or 3 years of non-specific change

Disadvantages:

- non-quantitative
- no 'from-to' change class information

Figure 1

Diagram of Multiple-Date Change Detection using Write Function Memory Insertion (Jensen, 1994).

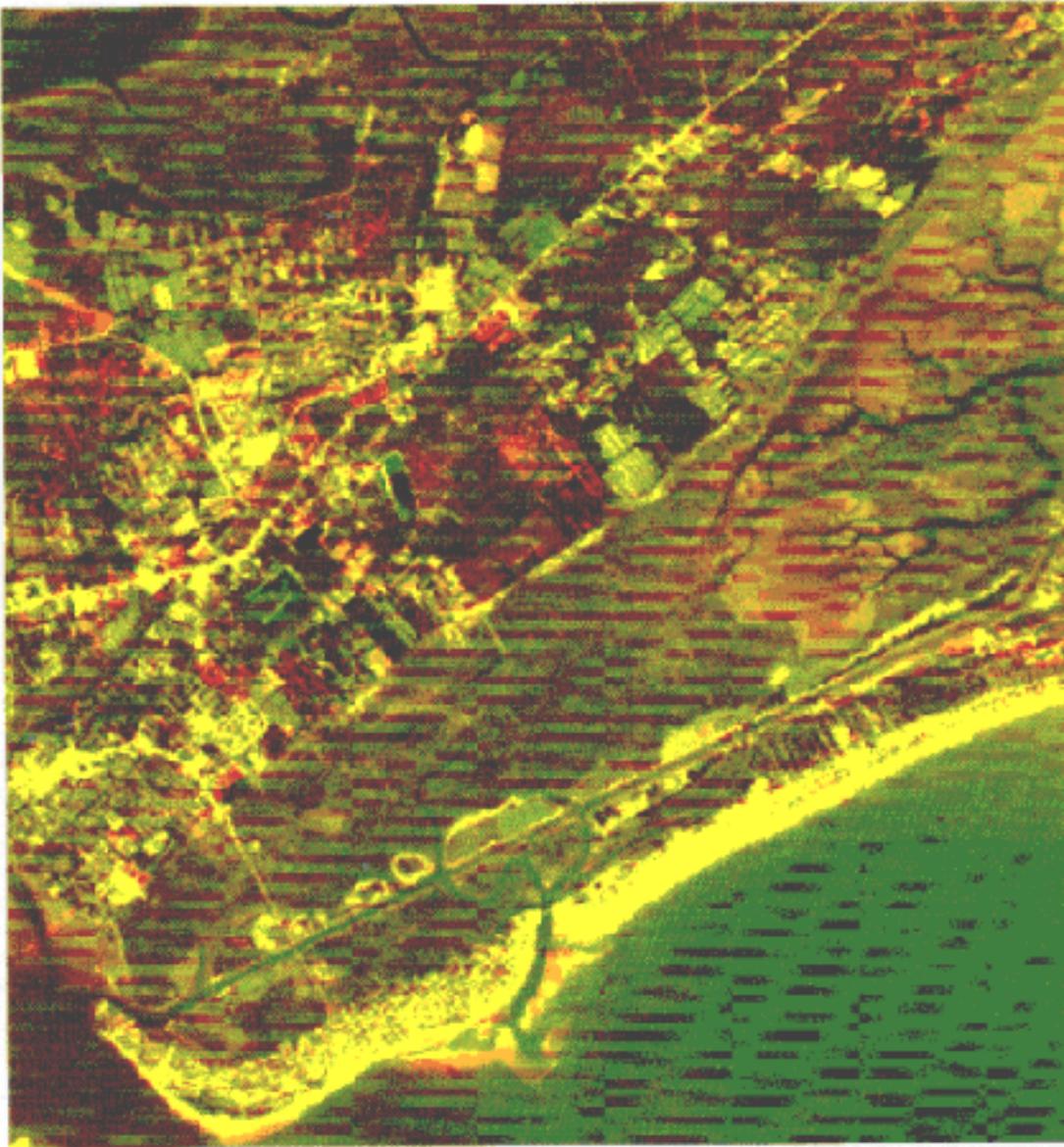
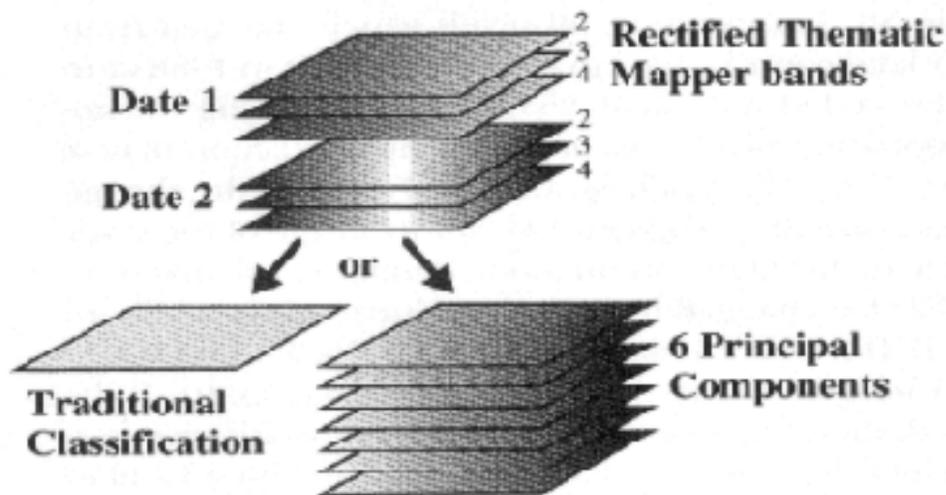


Figure 2

Example of Multiple-Date Change Detection using Write Function Memory Insertion using two dates of Landsat Thematic Mapper imagery of Fort Moultrie, S. C. Red image plane = TM band 3, 19 Dec 1988; green image plane = TM band 3, 9 Nov 1982; blue image plane = blank.

Multi-Date Composite Change Detection



Advantages:

- requires single classification

Disadvantages:

- difficult to label change classes
- no 'from to' change classes available

Figure 3

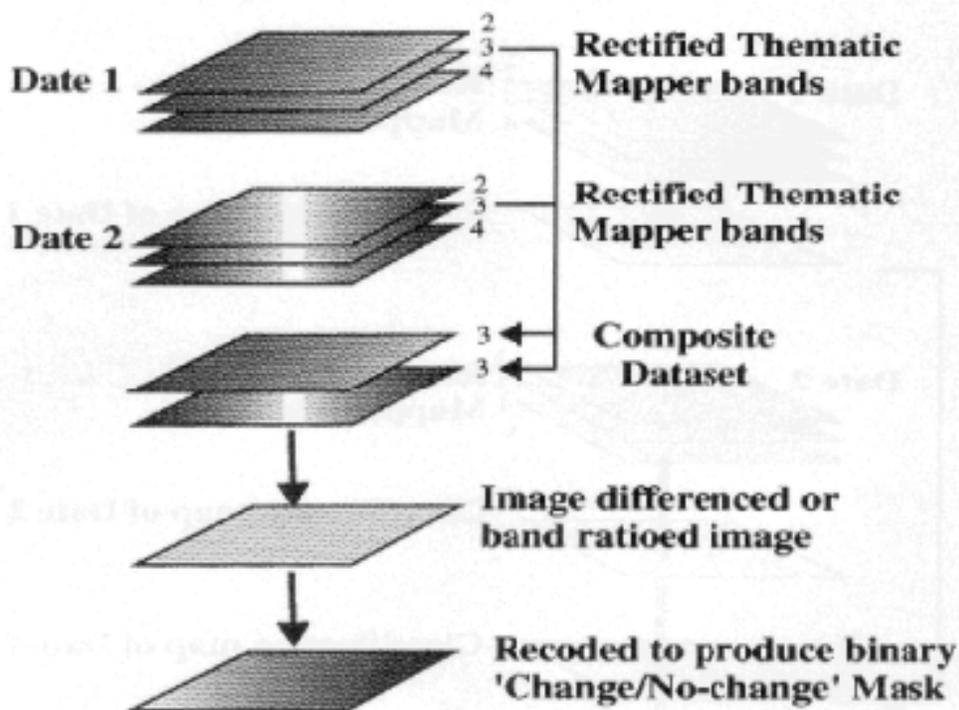
Diagram of Multiple-Date Composite Image Change Detection (Jensen, 1994).

Advantages of this technique include the possibility of looking at two and even three dates of remotely sensed imagery at one time as demonstrated by Jensen et al (1993b). Unfortunately, the technique does not produce a classified land cover database for either date and, thus, does not provide quantitative information on the amount of area changing from one land cover category to another. Nevertheless, it is an excellent analog method for quickly and qualitatively assessing the amount of change in a region which might help with the selection of one of the more rigorous change detection techniques to be discussed.

Multi-date Composite Image Change Detection

Numerous researchers have rectified multiple dates of remotely sensed imagery (e.g. selected bands of two Thematic Mapper scenes of the same region) and placed them in a single dataset (**Figure 4.**). This composite dataset can then be analyzed in a number of ways to extract change information. First, a traditional classification using all n bands (6 in the example in **Figure 4.**) may be performed. Unsupervised classification techniques will result in the creation of 'change' and 'no-change' clusters. The analyst must then label the clusters accordingly.

Image Algebra Change Detection



Advantages:

- efficient method of identifying pixels which have changed in brightness value between dates

Disadvantages:

- no 'from-to' change classes available
- requires careful selection of the 'change/no-change' threshold

Figure 4

Diagram of Image Algebra Change Detection (Jensen, 1994).

Other researchers have used principle component analysis (PCA) to detect change (Jensen 1986). Again, the method involves registering two (or more) dates of remotely sensed data to the same planimetric basemap as described earlier and then placing them in the same dataset. A PCA based on variance-covariance matrices or a standardized PCA based on analysis of correlation matrices is then performed (Fung and LeDrew 1987, 1988; Eastman and Fulk 1993). This results in the computation of eigenvalues and factor loadings used to produce a new, uncorrelated PCA image dataset. Usually, several of the new bands of information are directly related to change. The difficulty arises when trying to interpret and label each component image. Nevertheless, the method is of value and is used frequently.

The advantage of this techniques is that only a single classification is required. Unfortunately, it is often difficult to label the change classes and no "from-to" change class information is available.

Image Algebra Change Detection

It is possible to simply identify the amount of change between two images by band ratioing or image differencing the same band in two images which have previously been rectified to a common basemap. Image differencing involves subtracting the imagery of one date from that of another (**Figure 5**). The subtraction results in positive and negative values in areas of radiance change and zero values in areas of no-change in a new "change image". In an 8-bit (28) analysis with pixel values ranging from 0 to 255, the

potential range of difference values is -255 to 255. The results are normally transformed into positive values by adding a constant, c (usually 255). The operation is expressed mathematically as:

$$Dijk = BVijk(1) - BVijk(2) + c$$

where $Dijk$ = change pixel value

$BVijk(1)$ = brightness value at Tb

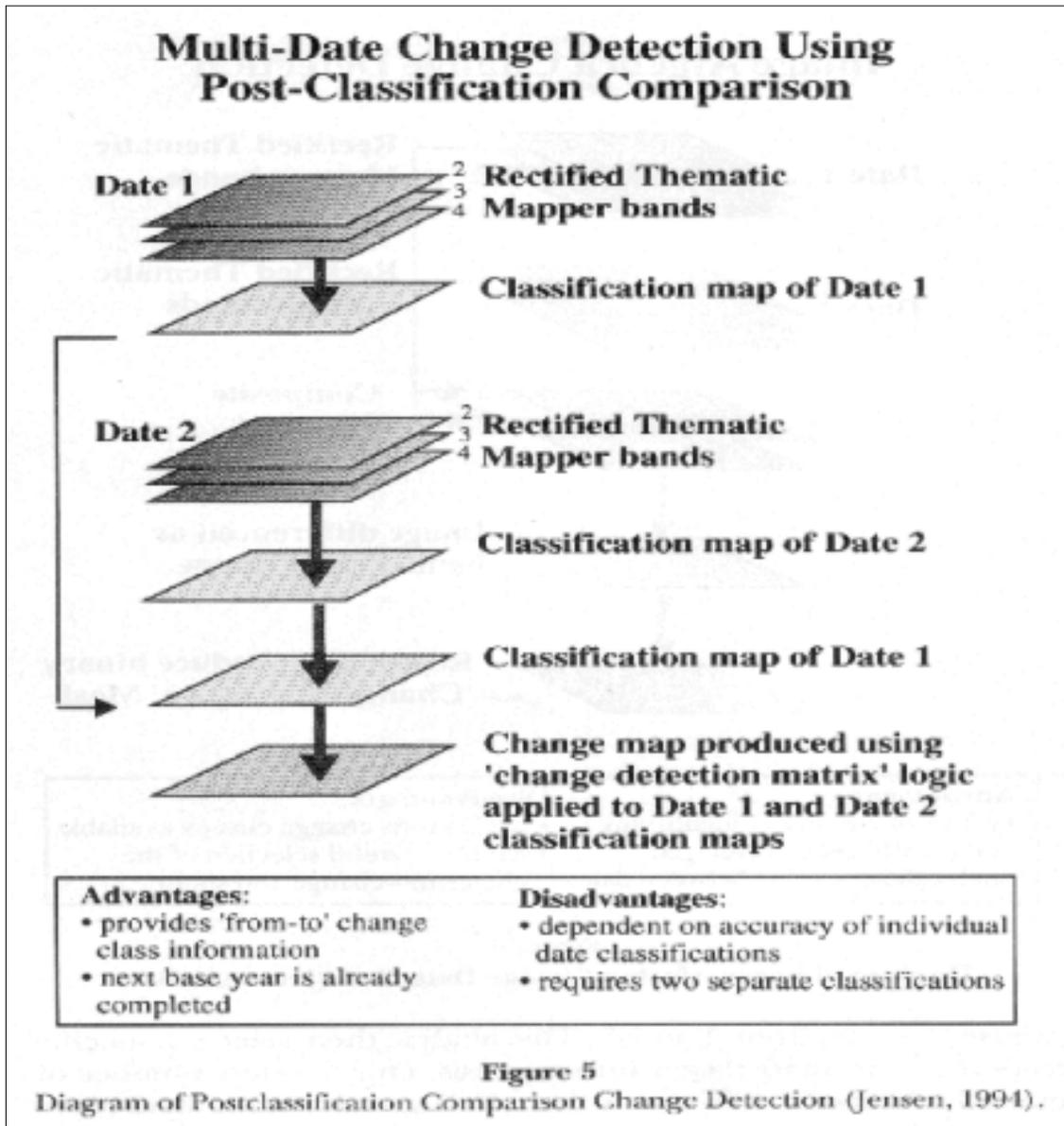
$BVijk(2)$ = brightness value at $Tb-1$ or $Tb+1$

c = a constant (e.g., 255).

i = line number

j = column number

k = a single band (e.g. TM band 4).

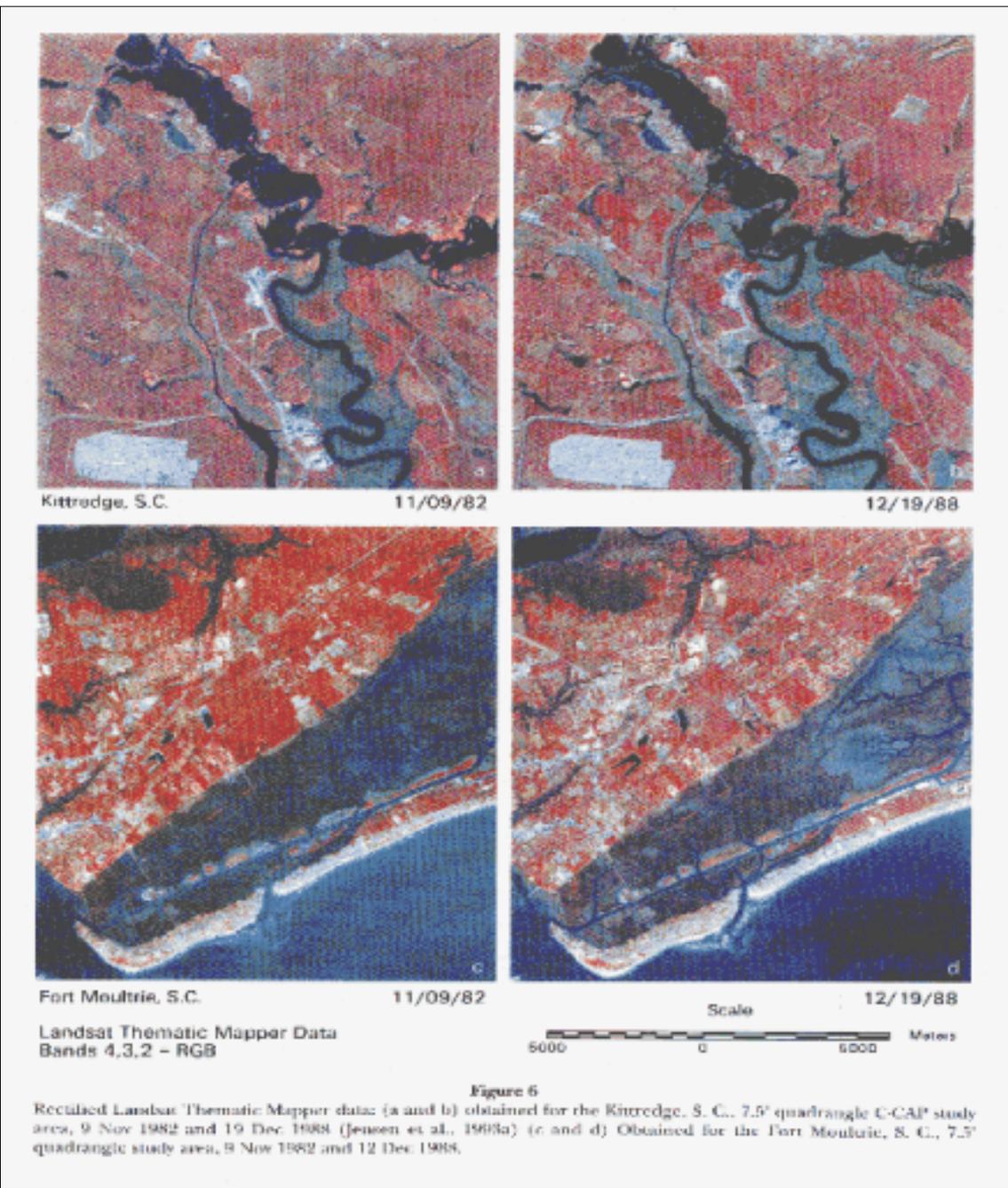


The "change image" produced using image differencing usually yields a BV distribution approximately Gaussian in nature, where pixels of no BV change are distributed around the mean and pixels of change are found in the tails of the distribution. Band ratioing involves exactly the same logic except a ratio is computed between Tb and $Tb+1$ and the pixels which did not change have a value of "1" in the change image.

A critical element of both image differencing and band ratioing change detection is deciding where to place the threshold boundaries between "change" and "no-change" pixels displayed in the histogram of the change image (Jensen 1986). Often, a standard deviation from the mean is selected and tested empirically. Conversely, most analysts prefer to experiment empirically, placing the threshold at various locations in the tails of the distribution until a realistic amount of change is encountered. Thus, the amount of change selected and eventually "recoded" for display is often subjective and must be based on familiarity with the study area. There are also analytical methods which can be used to select the most appropriate thresholds. Unfortunately, image differencing simply identifies those areas which may have changed and provides no information on the nature of the change, i.e. no "from-to" information. Nevertheless, the technique is valuable when used in conjunction with other techniques such as the multiple-date change detection using a binary change mask to be discussed in ["Multi-Date Change Detection Using a Binary Change Mask Applied to Tb-1 or Tb+1"](#).

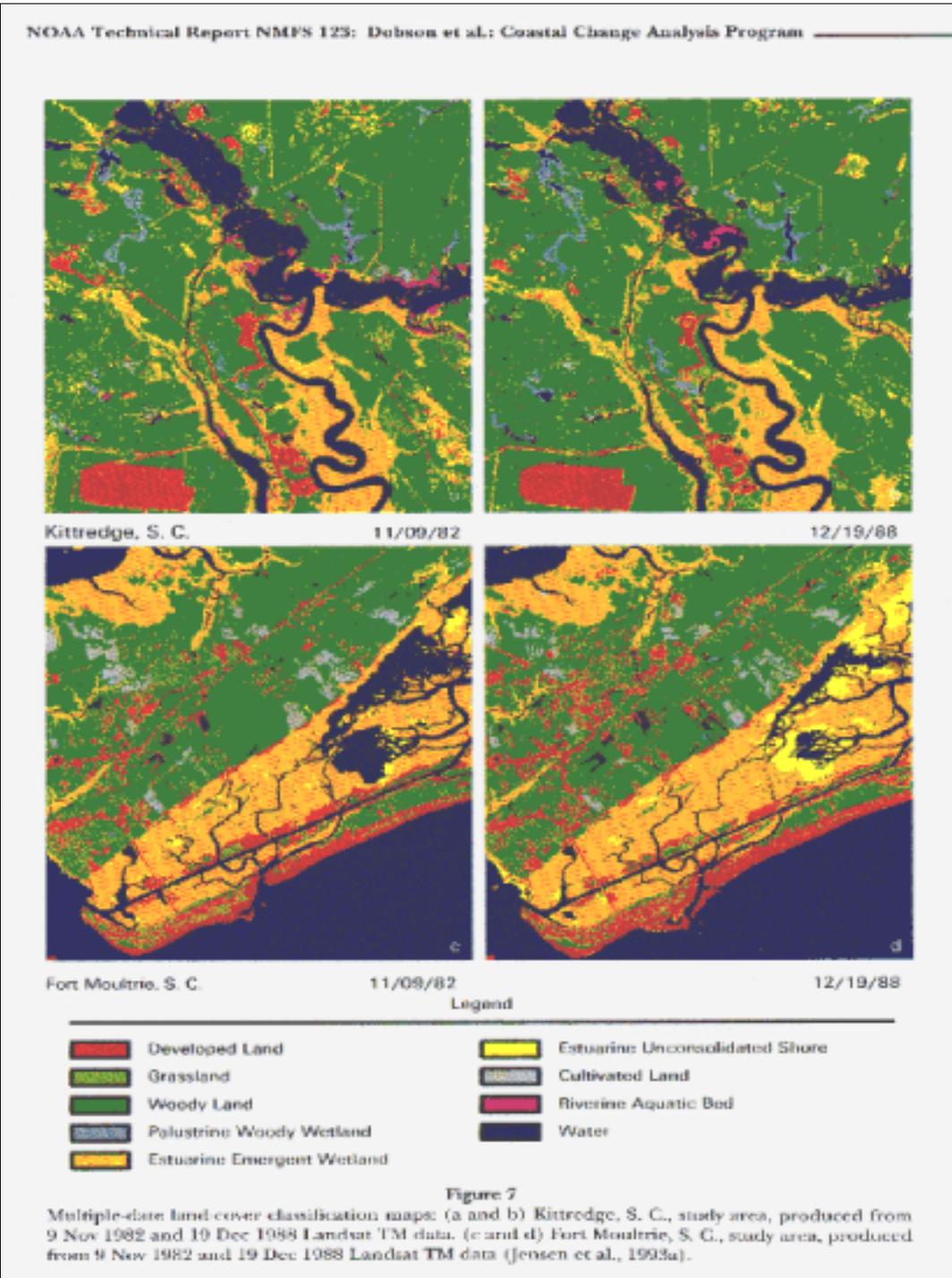
Post-Classification Comparison Change Detection

This is the most commonly used quantitative method of change detection (Jensen 1986; Jensen et al. 1993a) and may be used in regional C-CAP projects under certain conditions. It requires rectification and classification of each of the remotely sensed images (**Figure 6**). These two maps are then compared on a pixel by pixel basis using a "change detection matrix" to be discussed. Unfortunately, every error in the individual date classification map will also be present in the final change detection map (Rutchev and Velcheck 1993). Therefore, it is imperative that the individual classification maps used in the post-classification change detection method be extremely accurate (Augenstein et al. 1991; Price et al. 1992).

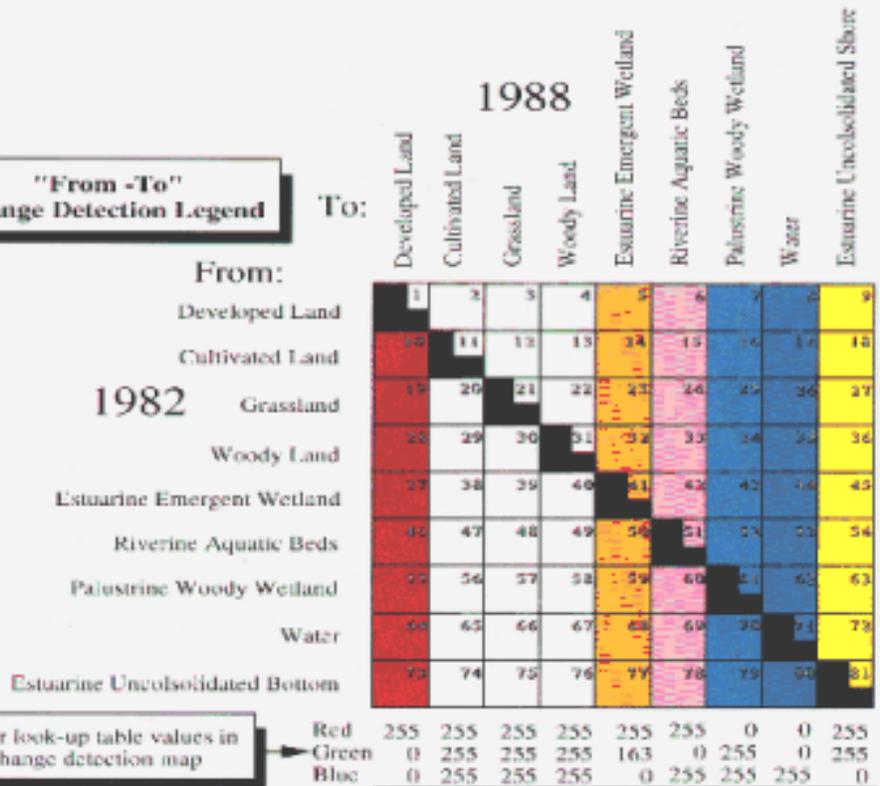


To demonstrate the post-classification comparison change detection method, consider the Kittredge (40 river miles inland from Charleston, S. C.) and Fort Moultrie, S. C. study areas (**Figure 7. abcd**) (Jensen et al. 1993a). Nine (9) classes of land cover were inventoried on each date (**Figure 8. abcd**). The 1982 and 1988 classification maps were then compared on a pixel by pixel basis using an n by n GIS "matrix" algorithm whose logic is shown in **Figure 9.** This resulted in the creation of "change images maps" consisting of brightness values from 1 to 81. The analyst then selected specific "from-to" classes for emphasis. Only a select number of the 72 (n^2-n) possible off-diagonal "from - to" land cover change classes summarized in the change matrix (**Figure 9.**) were selected to produce the change detection maps (**Figure 10. ab**). For example, all pixels which changed from any land cover in 1982 to "Developed Land" in 1988 were color coded red (RGB = 255, 0, 0) by selecting the appropriate "from - to" cells in the change detection matrix (10,19,28,37,46, 55,64, and 73). Note that the change classes are "draped" over a TM band 4 image of the study area to facilitate orientation. Similarly, all pixels in 1982 which changed to "Estuarine Unconsolidated Shore" by December 19, 1988 (cells 9,18,27,36,45,54,63, and 72) were depicted in yellow (RGB = 255, 255, 0). If desired, the analyst could highlight very specific changes such

as all pixels which changed from "Developed Land" to "Estuarine Emergent Wetland" (cell "5" in the matrix) by assigning a unique color look-up table value (not shown). A color coded version of the "Change Detection Matrix" can be used as an effective "from-to" change detection map legend (Jensen and Narumalani 1992).



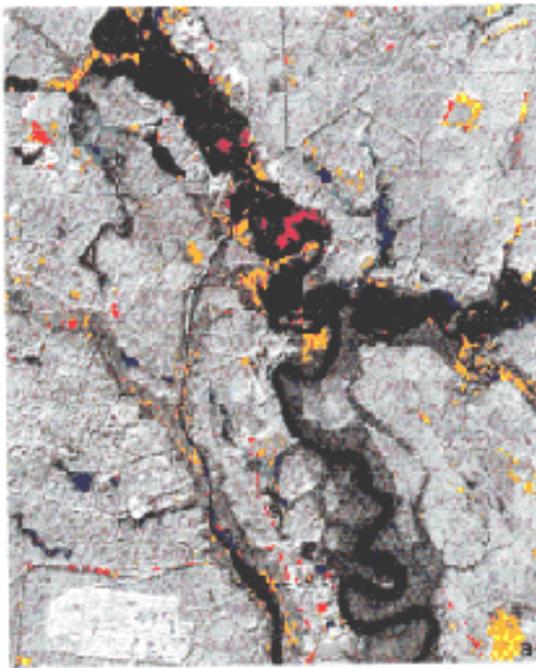
**"From -To"
Change Detection Legend**



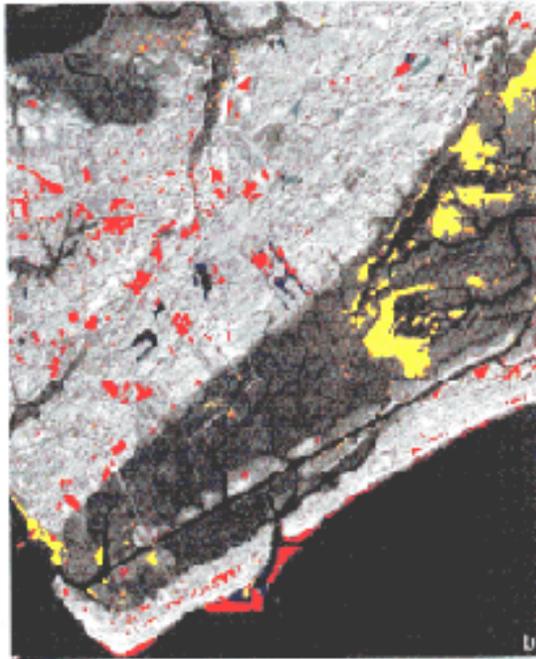
-  No change in landcover between dates, and not selected for display
-  Change in land cover between dates, but not selected for display
-  New Developed Land (cells 10,19, 28,37, 46,55,64,73) shown in red (RGB=255,0,0)
-  New Estuarine Unconsolidated Shore (cells 9,18,27,36,45,54,63,72) shown in yellow (RGB=255,255,0)

Figure 8

Change detection matrix. The basic elements of a change detection matrix may be used to select specific "from-to" classes for display in a "postclassification comparison" change detection map. There are $(n^2 - n)$ off-diagonal possible change classes which may be displayed in the change detection map (72 in this example) although some may be highly unlikely. The colored off-diagonal cells in this diagram were used to produce the change maps in Figure 9. For example, any pixel in the 1982 map that changed to Developed Land by 1988 is red (RGB=255,0,0). Any pixel that changed into Estuarine Unconsolidated Shore by 1988 is yellow (RGB=255,255,0). Individual cells can be color coded in the change map to identify very specific "from-to" changes (Jensen et al., 1993a).



Kittridge, S.C.



Fort Moultrie, S.C.

Changes in Land Cover 1982 to 1988

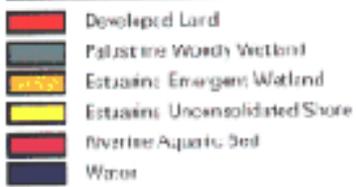
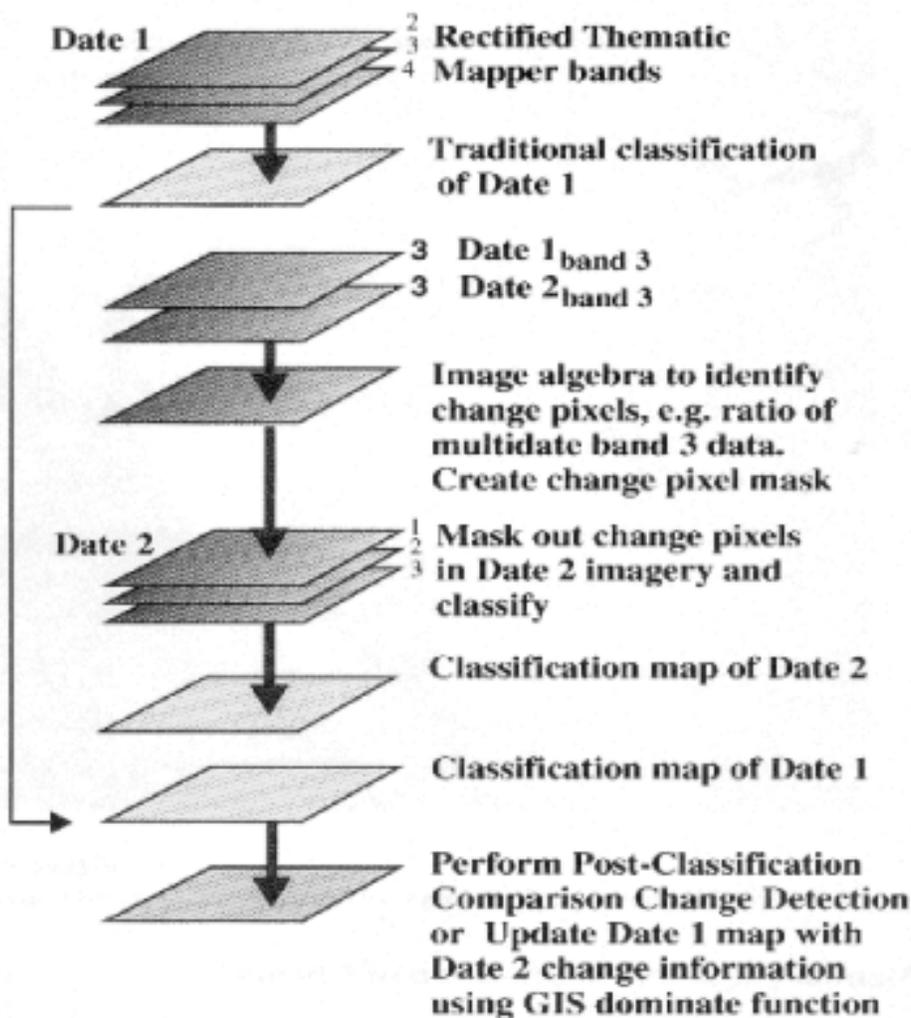


Figure 9

Change detection maps of the Kittridge and Fort Moultrie, S.C., study areas derived from analysis of 11 Nov 1982 and 19 Dec 1988 Landsat TM data. The nature of the changes laws selected for display are summarized in Figure 8. The change information is overlaid onto the Landsat TM band 4 image of each date for orientation purposes (Jensen et al., 1995a).

Multi-Date Change Detection Using A Binary Change Mask Applied to Date 2



Advantages:

- may reduce change detection errors (omission and commission)
- provides 'from-to' change class information

Disadvantages:

- requires a number of steps
- dependent on quality of 'change/no-change' binary mask

Figure 10

Diagram of Multiple-Date Change Detection Using a Binary Change Mask Applied to Date 2 (Jensen, 1994).

Post-classification comparison change detection is widely used and easy to understand. When conducted by skilled image analysts it represents a viable technique for the creation of C-CAP change detection products. Advantages include the detailed 'from-to' information and the classification map for each year. Unfortunately, the accuracy of the change detection is heavily dependent on the accuracy of the two separate classifications. The post-classification comparison is not recommended for C-CAP regional projects except under special circumstances, such as when different sensors are involved or when two separate organizations are classifying the same region at different times.

Multi-Date Change Detection Using a Binary Change Mask Applied to Tb-1 or Tb+1

This method of change detection is highly recommended for C-CAP regional projects. First, the analyst selects the base image, T_b . Date 2 may be an earlier image (T_{b-1}) or a later image (T_{b+1}). A traditional classification of T_b is performed using rectified remote sensor data. Next, one of the bands (e.g. band 3 in **Figure 11.**) from both dates of imagery are placed in a new dataset. The two band dataset is then analyzed using various image algebra functions (e.g. band ratio, image differencing, principal components) which produces a new image file. The analyst usually selects a "threshold" value to identify spectral "change" and "no-change" pixels in the new image as discussed in "[Image Algebra Change Detection](#)". The spectral change image is then recoded into a binary mask file, consisting of pixels with spectral change between the two dates, and these are viewed as candidate pixels for categorical change. Great care must be exercised when creating the "change/no-change" binary mask (Dobson and Bright 1993; Jensen et al. 1993a). The change mask is then overlaid onto T_{b-1} or T_{b+1} and only those pixels which were detected as having changed are classified in T_{b-1} or T_{b+1} . A traditional post-classification comparison (previous section) can then be applied to yield "from-to" change information. Hence, many pixels with sufficient change to be included in the mask of candidate pixels may not qualify as categorical land cover change.



Figure 11

Rectified Thematic Mapper imagery of the Metomkin Inlet area obtained on 21 Sep 1984 (Dobson and Bright, 1993)

Dobson and Bright (1991, 1992, 1993) utilized this change detection methodology to inventory change in the area surrounding the Chesapeake Bay using Thematic Mapper imagery obtained on September 9, 1984 and November 3, 1988 (the region centered on Metomkin Inlet is shown in **Figures 11. and 12.**). The 1988 base image was classified using traditional supervised classification techniques (**Figure 13.**). A

"change/no-change" mask was derived by performing image arithmetic on bands 3, 4, and 5 of the two date dataset. All change pixels were combined into a single change mask (**Figure 14.**) . The "change/no-change" mask was then overlaid onto the earlier date of imagery and only those pixels which were detected as having changed were classified in the earlier image. A "from-to" matrix similar to the one shown in **Figure 9.** was then used to produce a change map of the region (**Figure 15.**). Summary statistics for the region are found in Table 3. This process may be repeated with a later scene to determine successive change.



Figure 12

Rectified Thematic Mapper imagery of the Metomkin Inlet area obtained on 3 Nov. 1988 (Debuono and Bright, 1992).

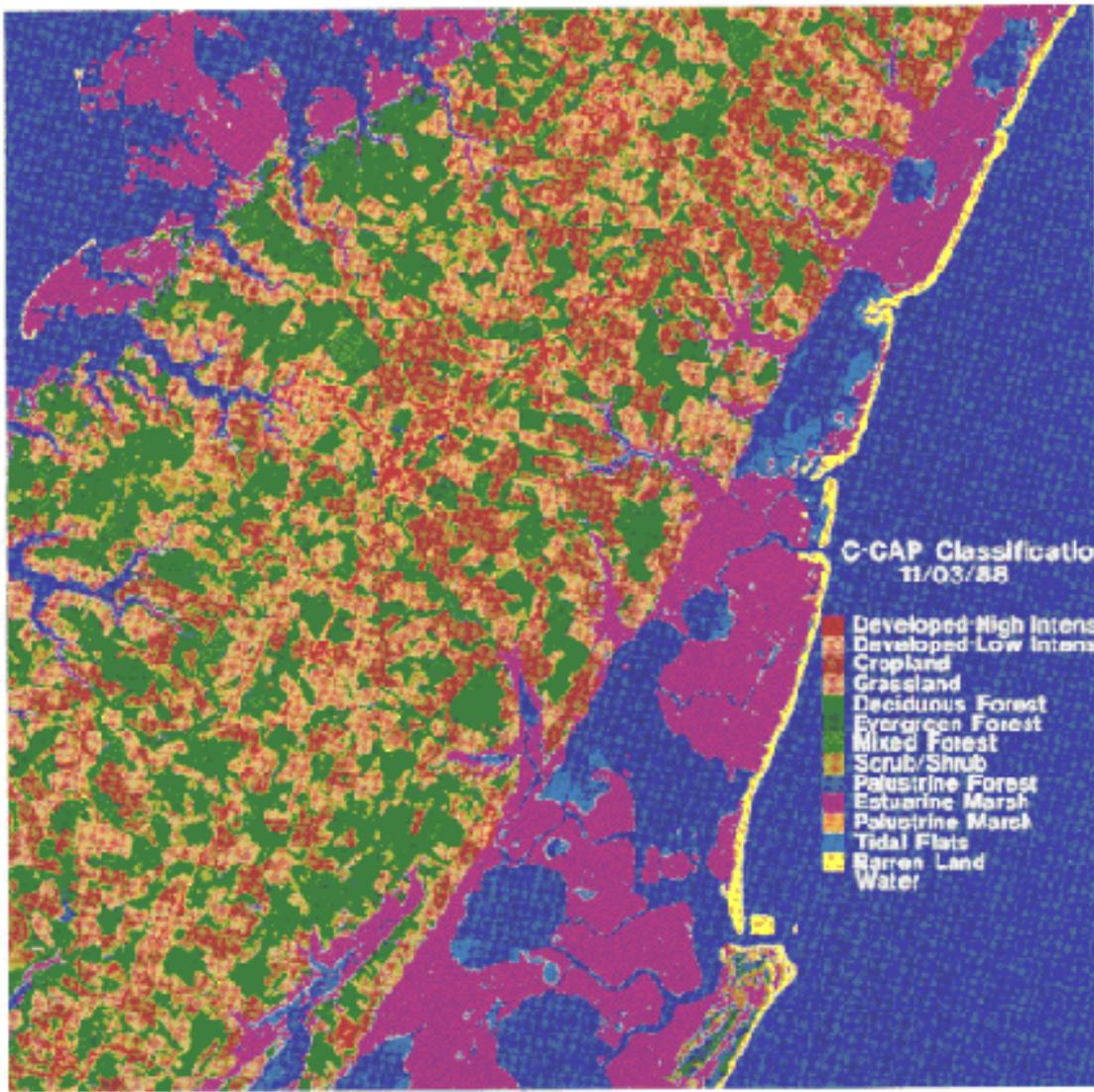
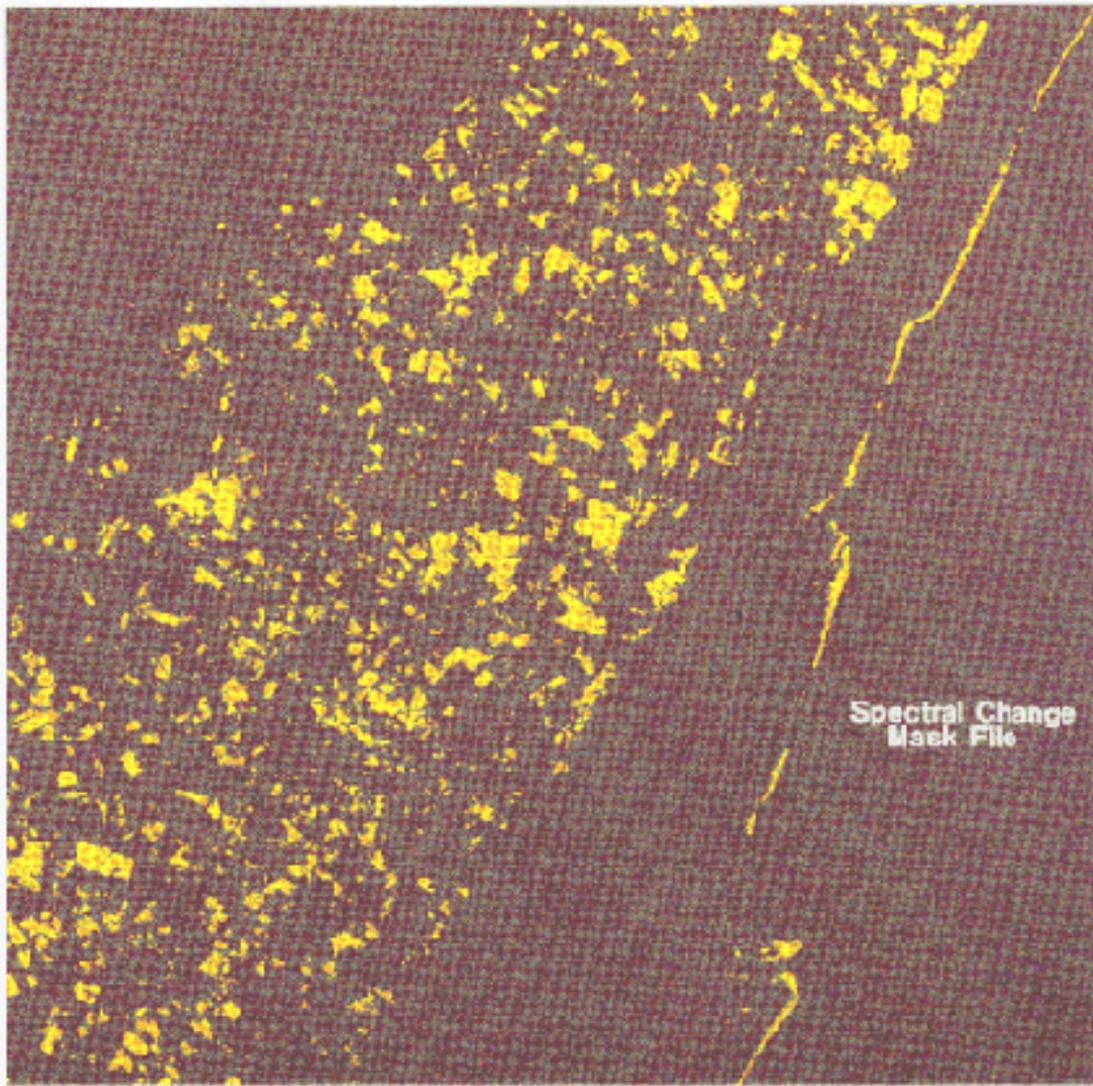


Figure 15

Classification map of 3 Plus 1000 Land Use Thematic Mapper imagery of the Metropolitan Watershed (Dahman and Bright, 1989)



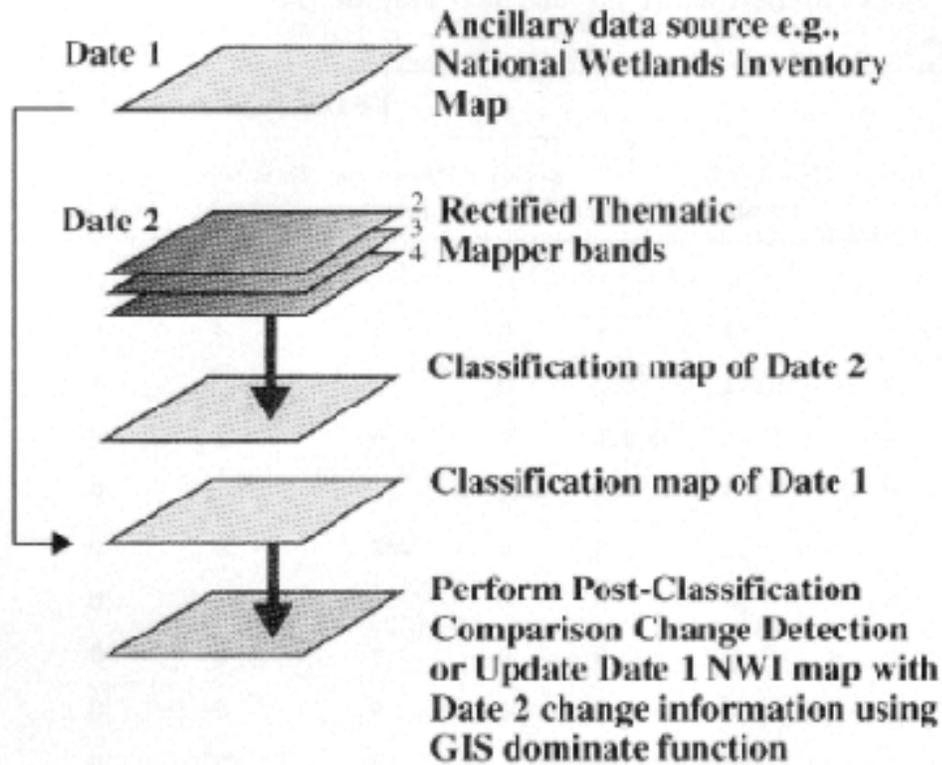
Spectral Change
Mask File

Figure 14

Binary "change/no-change mask" produced by image differencing TM bands 3, 4, and 5 of each date (Doisen and Bright, 1992).

the Tb information. Traditional "from-to" information can then be derived. As with any other post classification comparison, the accuracy of the change database is dependent on the accuracy of both input databases (C-CAP and NWI).

Multi-Date Change Detection Using An Ancillary Data Source as Date 1



Advantages:

- may reduce change detection errors (omission and commission)
- provides 'from-to' change class information
- requires a single classification

Disadvantages:

- dependent on quality of ancillary information

Figure 16

Diagram of Multiple-Date Change Detection Using Ancillary Data Source as Date 1 (Jensen, 1994).

Advantages of the method include the use of a well-known, trusted data source (NWI) and the possible reduction of errors of omission and commission. Detailed "from-to" information may be obtained using this method. Also, only a single classification of the Tb-1 or Tb+1 image is required. It may also be possible to up-date the NWI map (Tb) with more current wetland information (this would be done using a GIS 'dominate' function and the new wetland information found in the Tb-1 or Tb+1 classification). The disadvantage is that the NWI data must be digitized, generalized to be compatible with the C-CAP Coastal Land Cover Classification System, then converted from vector to raster format to be compatible with the raster remote sensor data. Any manual digitization and subsequent conversion introduces error into the database which may not be acceptable (Lunetta et al. 1991).

Manual On-screen Digitization of Change

Considerable amounts of high resolution remote sensor data are now available (e.g. SPOT 10 x 10 m, the aircraft mounted CASI - Calibrated Airborne Spectrographic Imager, NAPP- National Aerial Photography Program). These data can be rectified and used as planimetric basemaps or orthophotomaps. Often aerial photographs are scanned (digitized) at high resolutions into digital image files (Light 1993). These photographic datasets can then be registered to a common basemap and compared to identify change. Digitized high resolution aerial photographs displayed on a CRT screen can be interpreted easily using standard photo interpretation techniques based on size, shape, shadow, texture, etc. (Ryerson 1989). Therefore, it is becoming increasingly common for analysts to visually interpret both dates of aerial photographs (or other type of remote sensor data) on the screen, annotate the important features using heads-up "on- screen" digitizing, and compare the various images to detect change (Wang et al., 1992; Lacy 1992; Cowen et al. 1991; Westmoreland and Stow 1992; Cheng et al. 1992). The process is especially easy when a) both digitized photographs (or images) are displayed on the CRT at the same time, side by side, and b) they are topologically "linked" through object-oriented programming so that a polygon drawn around a feature on one photograph will have the same polygon drawn around the same object on the other photograph. Scanning aerial photographs unavoidably will reduce the spatial and spectral resolution of the source data. This loss may be significant in photographs of submerged features, which are subject to interferences from aquatic as well as atmospheric sources. As with other new technologies, demonstration of the appropriateness of interpretation of scanned photographs will be a critical step in expanding the C-CAP Protocol (Also see "Accuracy Assessment for Individual Date Classification of Water and Submersed Habitat Data", page #). The manual on-screen approach is recommended as a useful adjunct to other change detection methods. Its principle drawback is the time required to cover large regions in such a labor-intensive fashion.

Selecting Appropriate Classification Algorithms

C-CAP requires that the classification procedures used as part of the change detection process be approved and documented. Selection of the classification algorithms used in each region will be based on the capabilities and needs of the regional participants. C-CAP assumes that the regional participants are experienced in image processing and mapping. If not, C-CAP will attempt to provide fundamental technical assistance on a case by case basis.

The previous section indicated that three of the seven most commonly used change detection algorithms are acceptable for C-CAP regional projects:

- Post-Classification Comparison
- Change Detection Using A Binary Change Mask Applied to Tb-1 or Tb+1
- Change Detection Using Ancillary Data Source as Tb

Each of these requires a complete pixel by pixel classification of one date of imagery and, at least, a partial classification of an additional date. Hence, it is instructive to review the C-CAP approved image classification logic which may be used in the regional projects.

Supervised and Unsupervised Image Classification Logic

The primary reason for employing digital image classification algorithms is to reduce human labor and

improve consistency. It is expected that regional analysts will have sufficient expertise to assess the advantages of alternative classification algorithms and to recognize when human pattern recognition and other types of intervention are necessary. In practice, it may be necessary to employ a suite of algorithms including both supervised and unsupervised statistical pattern recognition approaches. Currently maximum-likelihood classifiers often serve as a good first step, but new statistical approaches are being developed and implemented on a routine basis (Jensen et al. 1987; Hodgson and Plews 1989; Foody et al. 1992). It is important for analysts to remain flexible with regard to procedures and algorithms.

Standard supervised and unsupervised classification techniques have been available for more than 20 years and are well documented in texts by Jensen (1986) and Campbell (1987). In a supervised classification, the analyst "trains" the classifier by extracting mean and co-variance statistics for known phenomena in a single date of remotely sensed data (Gong and Howarth 1990). These statistical patterns are then passed to a minimum-distance-to-means algorithm where unknown pixels are assigned to the class nearest in n-dimensional feature space, or to a maximum-likelihood classification algorithm which assigns an unknown pixel to the class in which it has the highest probability of being a member. Great care must be exercised when selecting training samples (Mausel et al. 1990).

In an unsupervised classification, the computer is allowed to query the multispectral properties of the scene using user specified criteria and to identify x mutually exclusive clusters in n-dimensional feature space (Chuvieco and Congalton 1988). The analyst must then convert (label) the x spectral clusters into information classes such as those found in the C-CAP Coastal Land Cover Classification System. Training sites visited in the field and identifiable in the digital imagery are also indispensable when labeling clusters in an unsupervised classification. The following sections discuss C-CAP guidelines for collecting training and verification samples.

Selection of Training and Verification Samples for Supervised and Unsupervised Classification

Only training sites which were actually visited on the ground by experienced professionals should be selected for extracting the multispectral statistical "signature" of a specific class when performing a supervised or unsupervised classification. It is suggested that a minimum of five training sites per land cover class be collected. This creates a representative training set when performing supervised classification and makes labeling clusters much easier in an unsupervised classification. In addition to the image analysts, the field team should contain specialists in ecology, biology, forestry, geography, statistics, and other pertinent fields such as agronomy. Field samples should be stratified by land cover type and by various physical factors such as slope, elevation, vegetation density, species mix, season, and latitude. The polygonal boundary of all field sites should be measured using global positioning systems whenever possible, and the locational, temporal, and categorical information archived.

The collection of field training sites often requires multiple visits to the field. Some of the field sites may be used to train a classifier or label a cluster while a certain proportion of the field sample sites should be held back to be used for classification error assessment to be discussed.

The following materials are indispensable to a successful field exercise:

- Imagery geocorrected to a standard map projection
- Topographic Maps at 1:24,000 or largest available scale
- Global Positioning System (GPS)

- Aerial photographs

It is advisable to perform, at least, a cursory classification before initiating fieldwork. In this case, both raw and classified data should be taken to the field. The primary function of the cursory classification is to guide field workers in targeting the covers and signatures that are most difficult and confusing. Keep in mind that the vast majority of all cover will be easy to identify on the ground and on the imagery. Efficient use of field time provides for quick verification of easy cover types and maximum attention to difficult, unusual, and ecologically critical cover types.

Field investigators should anticipate the need to know, not only the geodetic coordinates of training sites, but also the layout of the road network that will provide access. It is advisable to imbed roadway information into the raw imagery. This can be done using the Bureau of the Census's Topologically Integrated Geographic Encoding and Referencing (TIGER) files. Imbedding is preferred rather than transparent overlay techniques which are cumbersome and difficult to use under field conditions.

C-CAP investigators have assembled and tested a field station based on a color laptop computer with commercial software. At present the software supports visualization of raster imagery (eg. satellite data, digital orthophotographs, scanned aerial photographs) and vector databases (eg. Tiger road networks, NWI wetlands). A version of the software soon to be available from commercial vendors will allow for realtime input of GPS coordinates. It will then be possible to follow field movements directly on the image and map data. The software also allows for completion of field forms on screen in the field. Preliminary tests are encouraging, but the field station is not fully operational at this time. One shortcoming, for example, is the poor performance of active matrix color screens in sunlight.

The Use of Collateral Data in Image Classification

The overriding goal is to produce accurate individual date classifications and change detection databases. Any information or operation that enhances data quality is generally encouraged. C-CAP does not endorse the notion that the use of collateral data in a remote sensing project is "hedging" or "fudging". Instead, the objective is to innovatively use collateral data to improve the accuracy of the C-CAP database.

There are many potential sources of collateral data including soil maps, NOAA coastlines (T-sheets), timber surveys, USGS digital line graphs, and digital elevation models (for elevation, slope, and aspect). These can be incorporated by masking, filtering, probability weighting, or inclusion in the signature file (Ryerson 1989; Baker et al. 1991). Depending on the importance of each category, analysts may use certain categories to overrule others (Jensen et al. 1993a).

The NWI is an especially valuable collateral database that may be of value when classifying wetlands. Regional analysts should incorporate NWI data to the maximum extent possible. NWI data are recognized as the most authoritative and complete source of wetlands land cover data (Wilen 1990). However, NWI maps are not temporally synchronized in each region and are not in a digital format for many regions. An approach based on complementary use of NWI and imagery will be an asset to both C-CAP and NWI. At a minimum, NWI maps and/or digital data should be used to define training samples, to check intermediate results, and to aid in the final verification of the wetlands portion of the C-CAP maps. NWI digital data may be used as a probability filter in the classification process. In this approach, C-CAP recommends an "innocent until proven guilty" attitude toward the NWI data. In other words, the NWI category is considered correct for a given pixel area for each time period, unless spectral signatures or collateral data suggest that the NWI category is incorrect or a land cover change has

occurred. Even if the NWI data were 100% correct at the time of NWI mapping, overriding by spectral data would be necessary to detect change over time. Ultimately, in turn, the C-CAP change detection database can assist NWI managers in determining the need for NWI updates.

Cartographic Portrayal of Individual Classification Maps and Change Detection Maps

C-CAP products must meet stringent cartographic standards. The following sections discuss the minimum measurement unit and its proper use when aggregating change information. Formats of classification maps and change maps must satisfy C-CAP criteria whenever hardcopy maps are produced.

The Concept of the Minimum Measurement Unit

The minimum measurement unit is a measure of both precision and accuracy of the input data. For most C-CAP regional projects the input data will be 30 x 30 m pixel data recorded by a Landsat TM sensor. The minimum measurement unit, however, combines the ability (e.g., sensor limitations) and effort (e.g., field verification) required to measure a category with the spatial precision and accuracy necessary to accomplish the intended use of the data. Each land cover category could potentially have a different minimum measurement unit based on the size of individual parcels and the distinctiveness of the signature. Thus, the minimum measurement unit differs from a traditional minimum mapping unit which by definition imposes a predetermined polygon (or pixel) size for all land cover categories (for example, a rule that all parcels of one hectare or larger will be mapped). This traditional approach is acceptable for manual mapping using analog aerial photographs but is difficult to apply to raster imagery. Regional analysts will be responsible for defining minimum measurement units, generally larger than a single pixel but no larger than three pixel dimensions on the short axis.

Regardless of the minimum measurement unit, change analysis will be conducted pixel by pixel. C-CAP protocol requires that the inherent resolution of the raw data must be retained throughout the classification and change analysis processes. Aggregation and filtering of pixels should occur only in regard to cartographic presentation of the completed change detection database.

Regardless of the techniques employed, the final database should be capable of representing land cover by class for the base time, land cover by class for each earlier or later time, and land cover change by class for each change period. The final database should contain the full change matrix (all "from" and "to" categories) for each change period.

Analog (Hardcopy) Cartographic Products

Hard copy maps of the final database are not specifically required by C-CAP, but they are certain to be of use when presenting the results. Often it is useful to produce a smaller scale regional map (usually requiring some pixel aggregation) to give an impression of the scope of the effort and several larger scale maps at full resolution to demonstrate the level of detail and to highlight notable findings. All maps should come directly from the final database complying with C-CAP protocols, but overlay or imbedding of ancillary data, such as DLG and Bureau of the Census TIGER data, is encouraged with proper notation.

If the statistical summary of changes is present on a map, C-CAP recommends that the numbers included in it always be calculated for the area shown on the map. It is not acceptable to associate the summary of

changes for one area (larger or smaller) with a map of another. The statistical summaries of the change detection matrix must always be calculated from the database at full resolution, rather than from the aggregated data of the plot file. It is not advisable to allow the numerical count of class area to float with the level of cartographic aggregation. Unless all counts are based on the full resolution database, some classes composed of small features may disappear at higher levels of aggregation. Map readers will become confused if matrix numbers change with aggregation for the same territory.

Technically, the minimum cartographic presentation is 1) a map for the base time, 2) a map showing gains by class, and 3) a map showing losses by class. A full classification for the earlier or later (non-base) time may be useful, but it is not essential to present the matrix of possible changes. Examples of some of these products are found in **Figures 7-14. (Table 4.)**

Table 4. Statistical summary of areal change (ha) by land cover class for the Metomkin Inlet area shown in **Figures 12-16.** Read across each row to find which categories the 1988 totals came from. Read down each column to find which categories the 1984 totals changed to. Bold numbers along the diagonal indicate the area that did not change from 1985 to 1988.

	Developed	Grass	Forest	Scrub	Palustrine Forest	Estuarine Emergent	Palustrine Emergent	Water	Bare	Total
Developed	1158	85	8	0	0	4	0	1	0	1256
Grass	0	21341	562	0	0	2	0	0	17	21922
Forest	0	165	18915	0	0	1	0	0	0	19081
Scrub	0	240	562	854	0	2	0	0	0	1658
Palustrine Forest	0	20	9	0	787	0	0	0	0	816
Estuarine Emergent	0	26	9	0	0	11587	0	13	8	11643
Palustrine Emergent	0	0	0	0	0	0	0	0	0	0
Water	0	4	0	0	0	2	0	37172	144	37322
Bare	0	19	0	0	0	23	0	124	507	673
Total	1158	21900	20065	854	787	11621	0	37310	676	94371

Chapter 4. Guidelines for Monitoring Submerged Land Using Aerial Photography

C-CAP Focus on Aerial Photography of SRV

Photic submerged land can support SRV (including salt requiring seagrasses and oligohaline and freshwater tolerant grasses and forbs), macroalgae, and coral reefs (See "[Water and Submerged Land](#)", and [Appendix 3](#)). The C-CAP Coastal Land Cover Classification (See Table 2) identifies

Marine/Estuarine Aquatic Beds, specifically, SRV, of primary importance to be inventoried and placed in the C-CAP database (Klemas et al. 1993). Many of the steps discussed in Chapter 3 to monitor Uplands and Wetlands are pertinent to monitor SRV. However, there are significant differences which cannot be ignored. Important considerations include:

- The mapping of SRV is primarily a photogrammetric task rather than a satellite task requiring an entirely different sensor system (aircraft, camera filter and film)
- aerial photography is not normally radiometrically (except for color balance between photographs) or geometrically corrected
- The time of day, sensor altitude, and flightline placement are very flexible, unlike fixed orbit satellite sensor systems
- Numerous environmental conditions must be considered (sea state, water clarity, water depth, low altitude atmospheric conditions), to optimize photography
- Aerial photographs are in analog format

These differences are so significant that it is instructive to focus on aerial photography of SRV.

Ancillary Categories of Submersed Habitat

Other types of submersed habitat classified by C-CAP can be monitored with guidelines similar to those presented here for SRV. At a minimum, regional cooperators are requested to map and conduct change analysis for SRV. Increasing the number of habitat types to be included in the study will be based on local or regional interest and support for the effort. For example a comprehensive mapping of SRV, macroalgae and coral reefs is underway in the Florida Keys (See ["The State of Florida, Department of Environmental Protection"](#)).

Ancillary Technologies for Collection of Submersed Habitat Data

Some successes have been reported with satellite imagery and a number of other technologies to monitor photic submerged land. At the present time, these technologies supplement and eventually they may replace aerial photography for change detection in SRV. Some of them are briefly mentioned here.

Satellite imagery has some advantages but other disadvantages compared to photography. Satellite data generally has greater spectral resolution than aerial photography, but lesser spatial resolution. Satellite imagery is already in a digital format whereas information derived from aerial photography must eventually be digitized in order to be quantitatively analyzed. Landsat and SPOT data have been successfully used to inventory some macroalgae such as the giant kelp, *Macrocystis pyrifera*, along southern California shorelines (Jensen et al. 1980; Augenstein et al. 1991). In clear shallow tropical waters with highly reflective substrate, Landsat imagery may discriminate sandy from coral reef or seagrass areas (Luczkovich et al. 1993) or provide an estimate of biomass for unispecific beds of *Thalassia testudinum* (Armstrong 1993). In the turbid estuaries of the eastern United States, Landsat and SPOT imagery can be used to detect some (e.g. large, dense, shallow) but not all of the SRV which is visible in the best aerial photography. Aerial photography is, in fact, often used as "ground truth" when interpreting satellite imagery. Because of their fixed orbital paths, it is only fortuitous when a satellite image is acquired under optimum conditions for inventory of SRV (See ["Environmental Considerations"](#)). For these reasons, aerial photography is the C-CAP imagery of choice for comprehensive mapping and change detection (Ferguson and Wood 1990, Orth et al. 1991, Thomas and

Ferguson 1990, Ferguson et al. 1992; Ferguson et al. 1993). Photointerpretation supported by surface level signature verification and species identification is qualitatively and spatially more reliable for SRV than are satellite based methods.

A number of technologies may provide valuable supplemental data to aerial photographic detection of habitat change. These include: CCTV on an airplane, small boat or remotely operated vehicle (ROV), side scan and down looking SONAR, new satellite sensors, airborne spectral scanners and digital video scanners, and digitized photography. Such new technology will be incorporated into the C-CAP guidelines as it is demonstrated to meet qualitative, quantitative, resolution and geographic positioning standards. At present, CCTV is effective for surveillance applications but georeferencing and rectification fall short of metric quality photography. Airborne multispectral scanners and digital cameras are technologies with applications in the demonstration stage of development.

Direct mapping of habitat borders can be performed with differentially correctable Global Positioning System (GPS) instrumentation, when the perimeter of that habitat can be visually observed or detected with the aid of instruments in the field. Differentially corrected GPS can provide positions of surface level data at an accuracy suitable to supplement or assess the accuracy of aerial photographic data. With differential correction, single position fixes with GPS are accurate to a circular error probable (CEP) of 5m 50% of the time. The methodology for using GPS in accuracy assessment and monitoring of SRV is a current research topic funded by C-CAP (**Table 5**).

Table 5. General Steps required to conduct regional C-CAP change detection projects to extract water and submerged land information using aerial photography.

-
- State the regional change detection problem
 - Define the region
 - Specify frequency of change detection (1 to 5 years)
 - Identify classes of the C-CAP Classification System
 - Consider significant factors when performing change detection
 - Remote sensing system considerations
 - Spatial resolution and scale
 - Flightline considerations
 - Spectral resolution and file/filter combinations
 - Temporal resolution and diurnal sun angle
 - The preferred C-CAP aerial photography system
 - Environmental considerations
 - Atmospheric conditions
 - Turbidity
 - Vegetation phenological cycle characteristics
 - Tidal Stage
 - Surface roughness and sun glint conditions
 - Interpret aerial photography to extract water and submerged land information
 - Acquire appropriate change detection data

- In situ surface level verification and basemaps
 - Aerial photography
 - Base Year (Time b)
 - Subsequent year (Time b-1 or b + 1)
 - Preprocess the multiple-date photography
 - Radiometric correction (color balance)
 - Optically register photography to planimetric base map
 - Select appropriate change detection algorithm(usually postclassification comparison)
 - Image Analysis
 - Monoscopic (interpretation of single photos or orthophotographs)
 - Steroscopic (analog or analytical)
 - Transfer polygons to planimetric basemap
 - Digitize polygons
 - Perform change detection using GIS algorithms
 - Highlight selected classes using change detection matrix
 - Generate change map products
 - Compute change statistics
 - Conduct quality assurance and control
 - Assess spatial data quality
 - Assess statistical accuracy of
 - Individual date classification
 - Change detection products
 - Distribute C-CAP results
 - Digital products
 - Analog (hardcopy) products
-

Aerial Photography of SRV

Film

The recommended film is Aerocolor 2445 color negative film. Second choices are Aerochrome 2448 color reversal film and Aerographic 2405 black and white negative film. A haze filter should always be used to minimize the degrading effect of haze on photographic images. We do not recommend infrared film for delineating SRV. In our experience in North Carolina with tandem cameras, Aerochrome 2443 false color infrared film, was much less effective than color film at recording benthic features in shallow, moderately turbid water. True color film gives more information than black and white or infrared film, is critical for initial mapping attempts in a new or unfamiliar areas, and may permit identification of species in some tropical areas. Color negative film also appears to be better than color reversal or black and white film for identification of habitat under moderately turbid or hazy conditions. Color transparency prints are dimensionally stable and are most amenable to illumination of dark areas of the photograph for viewing

under magnification. Paper prints are not as dimensionally stable as transparencies (i.e. are subject to stretching and shrinking) but are more resistant than transparencies to damage from handling when used for field work.

Metric Photography and Photographic Scale

Metric quality aerial photographs (63° of tilt off-nadir) are essential and should be acquired with a protocol similar to that employed by NOAA's Photogrammetry Branch (1980) to produce the highest quality data possible. The need for rectification of photography is minimized by precise control of aircraft altitude and orientation relative to the vertical during photography and by interpretation in stereo. Photography should be obtained at a scale appropriate to the areal extent of habitat, local water conditions, type of habitat being studied and resolution requirements for the resultant data. Scale is a compromise among resolution of signatures, coverage of habitat, inclusion of land features sufficient for horizontal control, and cost. Photographic scale should normally range from 1:12,000 to 1:24,000. For extensive areas of high and variable turbidity such as in Chesapeake Bay, and eastern North Carolina, 1:24,000 or 1:20,000 scale photographs may be adequate when the water is clear. For chronically turbid estuarine or brackish water areas, 1:12,000 or larger scale photographs obtained at times of minimal turbidity, may be required for acceptable visualization of submerged features. Small scale photography may be necessary to bridge habitat delineated in larger scale photographs to local horizontal control points on adjacent land features which are not included in the larger scale photographs. GPS onboard the airplane to position photographic centers during exposure may be used to reduce this limitation of larger scale photography. For extensive areas of relatively clear water such as the Florida Keys, a scale of 1:48,000 may be sufficient and cost-effective. This is a current C-CAP research topic (See ["The State of Florida, Department of Environmental Protection"](#)).

Flightlines, Reconnaissance Flights, and Photographic Overlap

Flightlines are planned with reference to aeronautical and nautical charts to include all areas known to have or which potentially could have SRV. The efficiency of photographic missions can be optimized by minimizing the number of flightlines and by contingency planning. Some airspace is restricted for military or other use, for example, and is indicated on aeronautical charts. Nautical Charts provide bathymetric data useful for designating potential habitat areas when combined with local knowledge of the depth of vegetated bottoms. Reconnaissance flights can provide valuable perspective on SRV distribution if timed to optimize visualization of shallow bottoms (See Section 5.2.4). Ideally, each photograph in a flightline records cultural and shoreline features required to register the image to the base map, about 1/3 of the exposure. This permits correction of photographic scale and orientation to the external reference system. At a scale of 1:24,000 (1" = 2,000'), a standard 9 x 9" aerial photograph has a coverage of 18,000' by 18,000'. Large areas (relative to coverage of a single photograph) of open water require parallel flightlines and bridging of the large scale photography to control points with the small scale photography, construction of towers, etc., to supplement horizontal control features, or inflight GPS positioning of photographic centers.

Overlap of photographs includes endlap of adjacent photographs along a flightline and sidelap of photographs along parallel flightlines. Sixty percent endlap allows stereoscopic interpretation, facilitates interpretation from the most central region of the photographs and compensates for loss of coverage due to sun glint in the photographs (Sun glint is the image of the sun reflected off the surface of the water. See "Sun Angle", page #). Sidelap of 30% ensures contiguous coverage of adjacent flightlines and produces a

block of aerial photographs which may be subjected to photogrammetric bundle adjustment if necessary.

Environmental Considerations

Knowledge of the study area that is important to a successful project includes: plant species comprising SRV, morphology and phenology of these plants, depth range and location of known habitat, locations with water depth potentially suitable for habitat, types and locations of benthic features that may confuse photointerpretation of SRV, seasonality of turbidity, weather, and haze, daily patterns in wind speed and direction, and progression of sun angle through the day. Primary and secondary seasonal windows and the day and time of conducting photography are selected to optimize the visibility of habitat in the photography. Surface waters in different locations and at different times of the year will be more or less sensitive to turbidity from local runoff, plankton blooms, and local resuspension of sediment, and surface waves. Seasonal and daily trends for haze, cloud cover and wind direction, duration and velocity, should be included in planning for photography. The decisions of when to have the aircraft arrive at the study area (within the seasonal window), and when to collect photography are based on NOAA, National Ocean Service tide tables, local knowledge of factors affecting water clarity and depth, and observation of recent weather patterns (precipitation and wind direction and speed), and water clarity. The final decision to photograph includes observations from the air.

Primary and secondary photographic windows should be one or two months in duration to assure the occurrence of optimal conditions for photography. For single day missions it may be possible to have the plane and flightcrew fly to the study area on the day of photography. In our experience in North Carolina, staging of the plane and flight crews to the study area several times for periods of several days was required to complete missions involving more than one day of actual photography.

Phenology

The best time of year to acquire photography is during the season of maximum biomass or flowering of dominant species, considering the phenologic overlap for the entire community. This is June for the SRV of the Pacific northwest and Atlantic northeast, April and May (for eelgrass in eastern North Carolina), and September for most of the other species of SRV in the eastern U.S.

Clouds and Haze

It is best to have no clouds and minimal haze. Thin broken clouds or thin overcast above the plane may be acceptable when these are determined by visualization from the air neither to cast shadows nor adversely affect illumination of the study area. Haze reduces illumination and clarity of the image of benthic features being recorded in the photograph. Cooperators are referred to the Aerial Photographers Clear Day Map, U.S. Department of Commerce, Environmental Data Service.

Turbidity

Aerial photography should be conducted when turbidity is low. Care should be exercised in areas adjacent to sources of suspended sediment and nutrients. Data collection should be avoided during seasonal phytoplankton blooms or immediately following heavy rains or persistent strong winds. Potential days for photography are those during the photographic window for which high water clarity is expected, based on local experience, recent weather patterns, and surface level observation. The flightcrew should confirm water clarity from the air on the day of photography.

Tides

Generally, aerial photography should be collected within ± 2 hours of the lowest tide as predicted by the NOAA, National Ocean Service tide tables although factors affecting water depth and water clarity should be considered simultaneously. In general, extreme low tide, which may be -0.5 to -1.0 or more meters around the coast of the U.S. is preferred, if compatible with other constraints. In some estuaries there is a significant 'lag' in tidal stage which should be considered for data acquisition.

Wind and Surface Waves

No wind and waves is best. Low wind (< 10 mph) may be acceptable. The direction, persistence and fetch (the distance that wind can blow unobstructed over water) and recent wind events should be taken into account. Breaking waves and associated turbidity, white caps, lines of bubbles, and/or floating debris should not be visible from the air or in the photographs. For some areas, ocean swell can be an important consideration and should not exceed 3 feet.

Sun Angle

Sun angle affects the illumination of benthic features and sun glint and shadows from tall shoreline features in the photographs. A sun angle of 20-25° is optimal to record benthic features (Keller 1978). A sun angle of 15 to 30° is recommended by C-CAP. This interval maximizes the time for photography considering both the illumination of submerged features and sun glint. Sun angles above 15° illuminate the bottom sufficiently for photographic purposes. Sun glint also increases with sun angle but precludes visualization of benthic features where it occurs in the photograph. As sun angle increases sun glint also increases and moves from the edge toward the center of the photograph. Loss of coverage due to sun glint at sun angles of up to about 30° is compensated (to assure monoscopic coverage, at a minimum) by the recommended endlap of 60% (See "Flightlines, Reconnaissance Flights, and Photographic Overlap", page #). Eighty percent endlap will improve coverage when high sun angles cannot be avoided. Photography at sun angles above 30° is not recommended. Sun glint is minimized when the sun and land are on the same side of the plane because sun glint does not occur on land. Shadows from tall objects on shore such as trees, however, can preclude visualization of benthic features and may be a factor when the land and sun are on the same side of the plane.

Photointerpretation of SRV

Habitat defined by the presence of SRV can be interpreted from metric quality aerial photographs exposed as recommended in the previous sections. The accurate identification of SRV in aerial photographs requires visual evaluation of the fundamental elements of image interpretation (tone, color, contrast, texture, shadow etc.). It also requires extensive experience at ground level in the study area; the photographic images of habitat and non-habitat features vary in ways which cannot readily be modeled, described or communicated. Training for an habitat change analysis effort includes: literature research, discussions with local ecologists and biologists, site visits on foot, swimming (snorkel or SCUBA), or small boat, overflights in a small plane, and examination of historical aerial photographs of the area. Training of photointerpreters is active throughout the life of the project.

SRV is observed best using stereo pairs of photographs and high quality stereoscopic instruments (e.g. Wild, AVIOPRET, APT2, stereoscopes). Polygons are traced on overlays fixed to each photograph. To be delineated as habitat, recognizable and verified signatures of SRV must be present in the photographs.

SRV (and other benthic features) in a given area will present a variety of signatures depending upon species present, bottom sediment, depth, season, haze, clouds, water clarity and surface disturbances, and sun angle at the time of photography.

The designation of a given area as SRV is a function of minimum detection unit, minimum mapping unit, and its proximity to other SRV. Assuming a photographic scale of 1:24,000, high quality optics, high resolution film and ideal conditions (e.g. dense clusters of large vigorous shoots growing on light-colored sediment in shallow, clear, calm water), it is usually possible to have a minimum detection unit of approximately 1 m. All detected SRV which appear to be in a continuum with adjacent SRV in an area which exceeds 0.03 hectare will be mapped as a single polygon. The minimum mapping unit is the smallest area to be mapped as habitat. At the C-CAP map scale of 1:24,000, the minimum mapping unit is 0.03 hectare for SRV (i.e. a diameter of about 0.8 m on the map represents a diameter of about 20 m or an area of about 0.03 hectares on the ground). Therefore, isolated groups of shoots with a diameter of less than 20 m may be detected but not mapped as habitat. The presence of SRV signature in the photograph defines habitat if: 1) the total area exceeds 0.03 hectare; 2) no unvegetated discontinuities such as dredged or natural channels partition the distribution into spatial units less than 0.03 hectare; and 3) unvegetated areas between plants are not large relative to the minimum mapping unit. Unfortunately, not all areas of SRV can be detected when photographic conditions are less than ideal. Due to the constraint of the minimum mapping unit and the possibility of suboptimal photography, delineations of SRV will tend to be conservative. The degree of underestimation depends upon the atmospheric and hydrographic conditions at the time of photography, the experience of the photointerpreter, and the nature of the subject area.

Optimizing conditions for photography will minimize underestimation of SRV, particularly in areas that are intrinsically more difficult to interpret. Where habitat edges are clearly distinct in superior quality photography, they may also be detected in inferior quality photography (e.g. high biomass of SRV along a clear water channel with a steep bank of light-colored sediment). In other cases where the edges are not clearly distinct in superior quality photography they are likely to remain undetected in inferior photography (e.g. low biomass of SRV growing on a shallow depth gradient of deep, turbid water over dark-colored sediment). The deep-water edge of habitat often will be difficult to delineate. This edge may also be at high risk for loss due to degradation in water quality that limits the illumination of the bottom with photosynthetically active radiation.

SRV with unrecognized signatures due to poor photographic conditions cannot be mapped as habitat unless the area is rephotographed or additional sources of data are incorporated into the data base. When photointerpretation is difficult or not possible, the preferred option is to rephotograph the area under better conditions. Although desirable, this may not be possible. Even under the best photographic conditions, delineation of all or part of some habitat polygons may require additional effort in regard to surface level verification or direct inclusion of surface level data. Polygon borders derived from surface level data must be so designated in the lineage data base for "truth in labeling" requirements (See ["Digital Product Description"](#)). Suitable surface level positioning techniques include GPS or more traditional survey positioning techniques that can be demonstrated to provide the positional accuracy required by C-CAP.

Within a polygon of SRV, the extent of coverage of the bottom by shoots of SRV and the pattern of distribution of the shoots or bed form (e.g. circular, doughnut-shaped, irregular patches and or continuous cover of SRV) reflects the interaction of biotic, physical, and anthropogenic factors. Coverage and bed form can be estimated from aerial photographs but is not a requirement of C-CAP. An example of an

index of coverage is an adaptation of the crown density scale originally developed to categorize coverage by the crowns of trees in forests (Orth et al. 1991). Coverage indices and bed form identifications are affected, however, by factors such as water depth and brightness of bottom sediments. The degree of contrast between shoots and exposed sediment and clarity of the photographic image determines the minimum detection unit of features within SRV. Comparison of habitats with different depths, water clarity or substrate brightness, therefore, is problematic. Analysis of change over time at a given location may be useful but requires consistent photographic conditions and field verification. Changes in coverage or bed form over time in a given location may indicate changing conditions in that habitat polygon or disturbances such as scaring by the propellers of boats.

Some data including species, biomass, productivity, functional status, and health of SRV may not be interpretable from the aerial photographs. Species identification is not possible from aerial photography in temperate areas such as North Carolina and the Chesapeake Bay. In some tropical areas, species distributions and photographic signatures may be sufficiently distinct to discriminate by species.

Field Surveys

Species and Habitat at Randomly Selected Stations

Locations selected by stratified random sampling of potential habitat are observed for SRV species and presence or absence of aquatic bed during the same season and preferably within one year of the photography. Stations are stratified by water depth and water body. Water depth determines if sampling can be accomplished by wading, snorkeling or SCUBA. Clear water with a bottom depth of ≥ 2.5 meters or somewhat shallower turbid water may require SCUBA. Stratification permits flexibility in sampling intensity and effort (sampling by SCUBA requires special training and resources and takes about twice the time per station). Bathymetry and reference coordinates in NOAA nautical charts of the study area facilitate selection and positioning of stations. Navigation to stations is with GPS. The spatial density of points are adjusted according to the resources and scale of the project (e.g. an average of 1.5 to 2.5 nautical miles from station to station in North Carolina). Great care is taken to include all locations of potential habitat in the surface level survey. SRV is limited to water depths less than about 2 m at mean lower low water (MLLW) for Chesapeake Bay. A similar depth limit was determined for that habitat in eastern North Carolina. To determine that depth in North Carolina, potential habitat was sampled to water depths of 10 feet MLLW (Ferguson and Wood 1990). SRV is not known to occur seaward of the barrier islands in North Carolina. In sharp contrast, the maximum depth for SRV is 9 m off the northwest coast of Florida.

The presence or absence of aquatic beds and species of SRV are determined within an area equal to the minimum mapping unit and centered around the nominal station location. If SRV are present, visual observations of the number, size and distribution of groups of shoots are recorded. These data are translated into an assessment of the presence or absence of an aquatic bed at the station considering the spatial distribution of SRV relative to the minimum detection and mapping units. The goal is to assess presence data in a manner relevant to photointerpretation (See "Photointerpretation of SRV", page #). Ancillary data recorded are: water depth, salinity, water clarity, latitude and longitude, and descriptions of benthic sediment, algae, animals or animal shells, boulders etc. A GPS position fix is taken to be differentially corrected (post processing) to a CEP of 5 m. If the station data are not required to verify photointerpretation (See below), they can be used to estimate the accuracy of the habitat data (See ["Recommended Accuracy Assessment Test"](#)).

Signature Verification and Supplemental Spatial Data

Locations selected from the photographs are observed during the same season and within one year of the photographic mission. The purpose of this survey is to resolve uncertainties in the photographs and, if necessary, collect surface level data for inclusion in the spatial data base. Surface level data intended to augment photointerpreted data require differentially corrected GPS positioning to a CEP of 5 meters.

Base Maps and Registration of Habitat Polygons

Accurate and current planimetric base maps of coastal land features are essential for georeferencing (establishment of geographic location) and scaling polygons of habitat interpreted from aerial photographs. C-CAP recommends: 1) use of the most accurate and current base map available for the study area and 2) use of the most cost effective technology to apply local horizontal control to interpreted data by registration of the photographs to base maps. The base map and the registration technology may vary regionally.

Planimetric Base Maps

The accuracy of the base map used for local horizontal control places a limit on the accuracy of the C-CAP product. The two base maps broadly available are NOAA shoreline and USGS 7.5' topographic maps. NOAA, NOS produces highly accurate shoreline maps based on tide-coordinated and fully rectified photography (Swanson 1949; Ellis 1978; Slatina 1980; NOAA Photogrammetry Branch 1989; Crowell et al. 1991). When available and current, NOAA shoreline and coastal data should be used for C-CAP projects. These data, available in graphic and digital form, are products of the NOAA Coastal Mapping Program. Copies of these data are available from NOAA/NOS. Shoreline data are produced from tide-coordinated photographic data and ground level survey data by the Photogrammetry Branch of NOAA/NOS and meet or exceed National Map Accuracy Standards. Horizontal ground control meets or exceeds 3rd order, class I specifications found in the geodetic control standards (Federal Geodetic Control Committee 1984). The Coastal Mapping Project of the Photogrammetry Branch provides data that depict the delineation of the mean high water line, the limit of emergent vegetation (apparent shoreline) and/or cultural shoreline, and in some areas, e.g. North Carolina, the approximate mean lower low water line. NOAA, NOS, shoreline data are a data source for NOAA nautical charts and USGS topographic maps. Coverage of the U.S. coastline is not complete, however, and for some areas the data may be dated.

In some locations, USGS 7.5' topographic maps may be the only base maps available at a scale of 1:24,000. These maps delineate the high tide line and cultural features and may meet C-CAP requirements. In many instances, however, these maps are out of date and temporal changes in shorelines may cause problems in the application of local horizontal control to compile the habitat polygons (Ferguson and Wood 1990). This can reduce the positional and scaling accuracy of habitat data which is critical for change analysis (See "Recent Photography", page #). Care should be taken to determine the effective date of coastal features in these maps. Updates of these maps generally include cultural but not natural changes in shoreline. Coverage of the coastal U.S. is almost comprehensive, but dated. In some coastal areas, 1:24,000 scale orthophotoquads have been published as an alternative to the topographic maps. Orthophotoquads at a scale of 1:24,000, are unsatisfactory for compilation from aerial photography in remote areas. Orthophotoquads do not have delineated shorelines which may be needed when the preferred cultural features are insufficient for the purpose of registration of the photograph to the map base.

Transfer of Polygons to the Map Coordinate Projection System

Polygons of habitat interpreted from aerial photographs are mapped into a standard map projection coordinate system. The Universal Transverse Mercator Projection is recommended. C-CAP protocol allows the polygons interpreted from aerial photography to be transferred onto planimetrically accurate basemaps using three approaches.

1.) Stereoscopically interpret the photographs and optically scale the polygons and photographic image to fit planimetric horizontal control in the basemap with a zoom transfer scope. This is the least expensive and often the most reliable approach. Habitat delineations drawn at the photographic scale through stereo viewing under magnification are transferred using camera lucida principles from the photographic overlay directly onto the planimetric basemap.

2.) Process the aerial photographs to become planimetrically accurate orthophotographs, interpret and directly trace habitat polygons onto the planimetric base map. Interpretation of the orthophotographs is performed using monoscopic airphoto interpretation techniques. The orthophotographs must be at the same scale as the base map or the images must be enlarged or reduced to the map scale. This approach applies orthophotographic rectification (Thrower and Jensen 1976) which corrects relief displacement in the original photographs and assures planimetric mapping results in the data base. Some loss of detail may occur since the orthophotography is a generation away from the original aerial photography. The process is expensive but accuracy is improved in areas with substantial vertical relief.

3.) Delineate and simultaneously rectify and digitize habitat polygons using an analytical stereo plotter. The 3-dimensional stereo model of the aerial photographs is leveled and scaled in the analytical plotter (AP) and the interpreter views a 3-dimensional landscape during photointerpretation. All polygonal interpretations are automatically stored in digital x,y coordinates in their proper planimetric position during photointerpretation (Welch et al. 1992), avoiding any error which might arise during information transfer in methods 1 and 2 discussed above. The polygon data are registered and digitized without errors which are associated with transfer in a zoom transfer scope or hand digitization. Unfortunately, analytical stereoplotters are expensive and require special training. Some additional expense to locate x,y and z control points may be necessary to successfully level the block of aerial photography. Recent advances in soft-copy photogrammetry allow analytical stereo plotter functions to be accomplished using UNIX type workstations and image processing software (e.g. ERDAS ORTHO-max). Therefore, this alternative will become more affordable and attractive in the future.

An adaptation of the third approach is being tested by NOAA and the State of Florida. Photointerpretation is done as in approach 1. Registration and digitization of the interpreted habitat polygons is completed in the AP. Due to the high expense of AP and the specialization of AP technicians, this option may be feasible for processing data from SRV interpreters who do not have direct access to or training on an AP.

Digitization of Habitat Polygons

Habitat polygons that have been transferred to the planimetric base map according to procedure 1 or 2 above require digitization to be incorporated into the C-CAP spatial data base. Digitization normally is accomplished using a digitizing tablet. Polygons are digitized using a digitizing table in point mode. The overlays are labeled according to the base map. Compilations are checked for clear delineation and cartographic acceptability of line work, existence of and consistency in feature attributes, and adequacy of horizontal control points. Compilations are checked along neat lines to confirm edge line match and label

match for polygons extending over adjoining maps. Any inconsistencies are brought to the attention of the map author.

Compilations are affixed to a digitizing table for georeferencing and data entry. The accuracy of the reference points, the four corners of the neat line and no less than four internal tick marks on the overlays, are checked to assure that control points are within ± 0.02 ". This translates to ± 40 feet or ± 12.2 m from its stated location. If tolerance is exceeded on any one point, new control points are selected, digitized and re-evaluated until all points test within tolerance. Information regarding the georeferencing error for each control point is recorded on a documentation form. In addition the technician records other information about the overlay manuscript such as scale, size, media type, source map information, and author.

Polygons are digitized with the cartographic style and accuracy that is represented on the source manuscript. A technician performs digitizing and data processing to map completion, including edge line matching, initial check plots, review, edits, and final check plots. All linework and labeling are reviewed using check plots produced at the source map scale. Each arc is checked for acceptance on a light table with the source map and the final check plot overlaid on the source map. Digitized linework should conceal original linework with exceptions for difference in line thickness, differences in media, and in subtle differences of horizontal control on the source map and in digital files. Unacceptable data is flagged, edited, and reviewed prior to acceptance into the digital database. A data layer specification form is completed for formal documentation at the conclusion of all digitizing.

Scan digitizing may be an acceptable alternative to hand digitizing and could be applied at one of two stages: 1) digitize polygons positioned on overlays of base maps, and 2) digitize polygons interpreted from individual photographs. Large format scanners would be required to scan an entire map, approximately 19 by 23", in one pass. A standard desktop scanner, 8.5 by 11", could scan the overlay from a single 9 by 9" photograph. In the latter case geopositioning might be accomplished digitally without the use of the zoom transfer scope. In either case, the digital product would have to meet the same positional tolerances described above for data entry with the digitizing tablet.

Change Detection With Aerial Photographic Data

The C-CAP objective of site specific change detection places greater emphasis on accuracy and precision of spatial data than required in one-time inventories or regional summaries of change. Methodology for monitoring site specific change on a statewide or regional scale is a recent development (Ferguson and Wood 1990; Orth et al. 1991; Ferguson et al. 1993). Quantitative historical data, with possible exceptions in Chesapeake Bay or spatially limited study sites, does not exist.

Recent Photography

C-CAP recommends post-classification change detection for SRV. Photographs taken in the same season of different years are independently interpreted, verified and compiled to the base map. In this case independence does not mean different photointerpreters, compilers, and field personnel but rather an avoidance of side-by-side comparison of the data until after classification is complete. Post-classification change detection can be accomplished graphically or polygons are digitized and compared using a geographic information system to detect spatial displacement and quantify change. Although simple in concept, the statistics of change analysis are not well understood. Development of consensus for statistical evaluation of qualitative or spatial change is a subject of ongoing C-CAP research.

As an expedient to post-classification change detection, photographs from different years are compared directly or photographs are compared to mapped polygons. Such comparison rapidly but subjectively can identify areas where change may have occurred. The determination of what constitutes significant change and the means to objectively quantify the degree of change remain to be determined.

Historical Photography

The earliest metric quality aerial photographs were acquired in about 1939. Prior to 1960, virtually all aerial photographs were black and white. Incomplete coverage, lack of coordination with tide, inappropriate scale, sun angle, and inappropriate time of year, or poor quality for visualization of benthic features often make these photographs unacceptable for a C-CAP change analysis. Interpretation of historical photographs is likely to proceed with limited or no concurrent surface level information for signature verification and should be attempted only by interpreters with extensive experience in the study area. Unless historical photography meets C-CAP requirements listed in "Aerial Photography of SRV" (page #) and is supported by surface level data as discussed in "Field Surveys" (page #), historical presence or absence of SRV at a given location may remain an open question. Some but not all SRV can be identified in less than optimal photography and be confirmed in the literature or memory of local residents. A visible signature for "bare bottom" or another non-habitat signature is required to interpret absence of habitat at the time of photography. Documentation of loss, as a result, may be more likely than documentation of gain of SRV with historical photography.

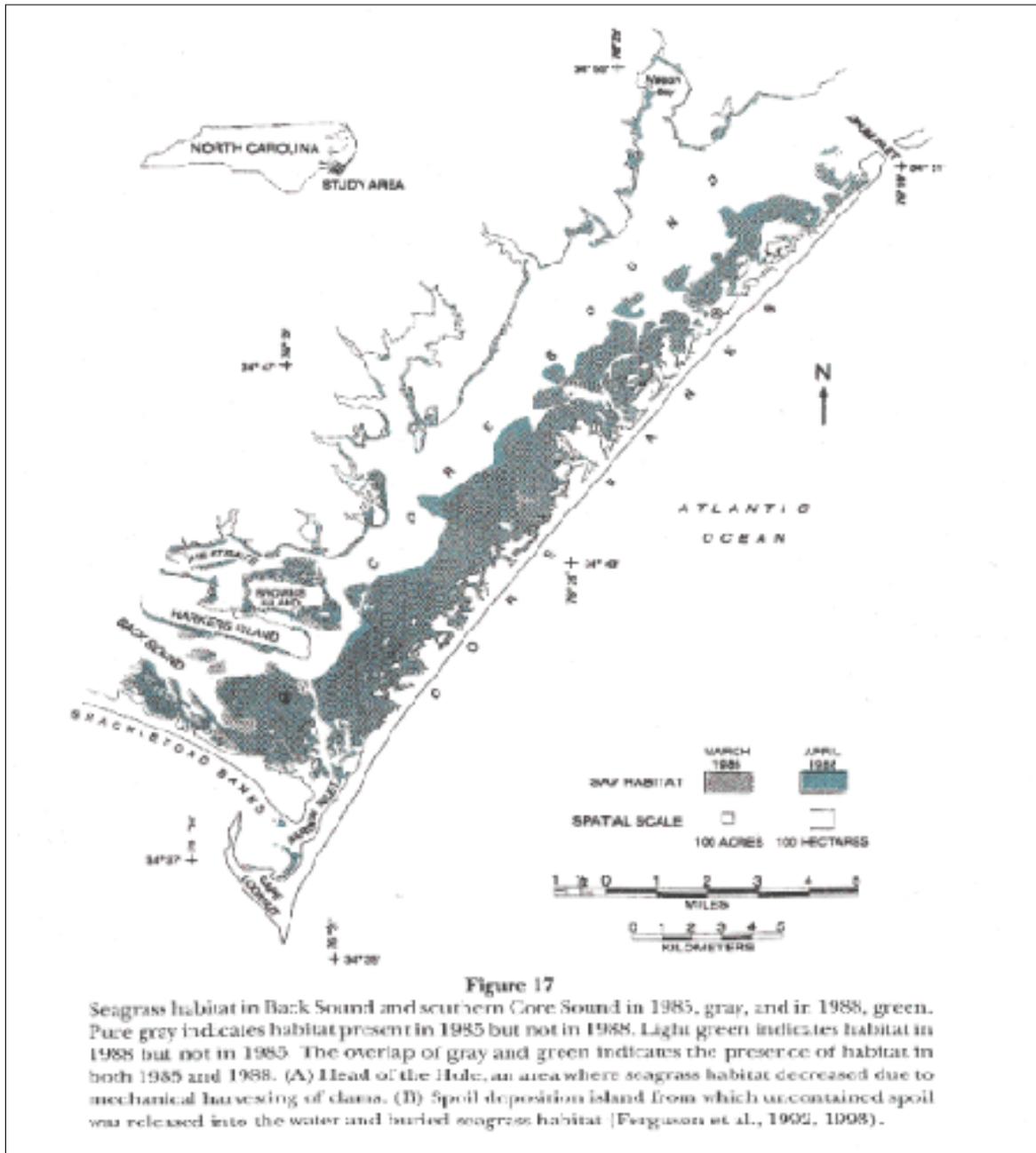
Historical photographs may contain limited but valuable information on occurrence of submersed habitat other than SRV. Canopies of the giant kelp, *Macrocystis pyrifera*, for example, are readily discernible in color IR photography because they have very high IR reflectance against a background of water that has no reflectance. The ease of photointerpretation of some macroalga allows historical photography to be used to identify habitat characterized by this and perhaps some other types of habitat.

The most complete and general (but not comprehensive) source for historical photography is the EROS Data Center in Sioux Falls, South Dakota. EROS records can be searched through the Earth Sciences Information Center (ESIC) of the U. S. Geological Survey (USGS). The searcher must supply coordinates or the names of USGS 7.5 minute quadrangles which locate the area of interest. The ESIC office conducts a microfiche or computer based search. Information produced includes: latitude and longitude, emulsion, scale, month, year, and source of the photography, cloud cover, camera and frame numbers. Sources of this photography are USGS, National Aeronautical and Space Administration (NASA), U.S. Fish and Wildlife Service (USFWS), Agricultural Stabilization and Conservation Service (ASCS), Soil Conservation Service (SCS), U.S. Forest Service (USFS), and some private companies. All historical photography identified in an ESIC search is reproducible. Substantial collections of historical photography may also be found in other federal or state agencies, universities, or private companies. These collections of photography may be available for reproduction, distribution, loan, or examination. Federal sources include Army Corps of Engineers (COE), U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), National Archives (pre-1956), and the Smithsonian Institution.

Change Detection of Seagrass Habitat in North Carolina

Ferguson et al. (1993) followed the C-CAP guidelines in Back Sound and southern Core Sound in North Carolina. That study demonstrated the feasibility of monitoring spatial change in SRV using C-CAP guidelines for large scale metric aerial photography, photointerpretation, geographic positioning and

post-classification change detection techniques. Aerochrome MS 2448 color-reversal film was exposed in March, 1985 at 1:20,000 and 1:12,000 scale. Aerocolor 2445 color negative film was exposed in of 1:24,000 in April, 1988. All aerial photography was obtained by the NOAA, NOS, Photogrammetry Branch. The photography was coordinated with low tide and sun angle and collected with minimal haze, no clouds below the aircraft, and no visible shadows from high clouds. Water was essentially free of white caps and clear enough for identification of vegetated and shallow unvegetated bottoms. Episodic wind, haze, local turbidity, and airborne pollen often precluded photography for one or more days. The sun angle during photography ranged from 15 to 30°. This sun angle localized sun glare to one edge of the photography while presenting illumination below the water surface. The aerial photographs were interpreted stereoscopically and the polygons were transferred to planimetric NOS shoreline maps with a zoom transfer scope. A graphical post-classification overlay approach was used to visually identify changes between years (**Figure 17.**). A gray tone in the chart indicates habitat present in 1985 but not in 1988. Light green indicates habitat in 1988 but not in 1985. The overlay of gray and green indicates the presence of seagrass habitat in both 1985 and 1988.



Summary statistics, obtained via automated geometric analysis of digitized video images of individual polygons (pixel size <0.03 hectare) revealed that seagrass habitat is a major resource in the study area, comprising about 35 percent of the subtidal land. Total area of habitat changed less than 6 percent from 7030 ha in 1985 to 6637 ha in 1988. Polygons along the mainland and Harkers Island tended to be linear and close to shore. Large broad areas of seagrass habitat occurred in the subtidal shallows east of Browns Island, north of Shackelford Banks, and west of Core Banks. The total number of habitat polygons was similar in the two years, 151 in 1985 and 149 in 1988. Reliability of detected change was conducted by reinspection of the photography and is summarized in Ferguson et al. (1993). Some areas of detected change were confirmed by surface level observations and two of these were associated with known anthropogenic disturbances. Some areas of detected change were confirmed but could not be associated with potential causes. Still others could not be confirmed and may have been due to variable quality in the photography. In a continuation of this study, the study area was rephotographed in 1992 and surface level verification of signature was completed in 1993. Data for all three years, 1985, 1988, and 1992 will be digitized and change will be assessed in a GIS.

Chapter 5. Quality Assurance and Control

Quality assurance and control (QA/QC) from data acquisition through final database compilation are the responsibility of each regional project team. Acceptance of the final database into the C-CAP archive and dissemination system are contingent upon demonstration that the project has complied with the mandatory requirements stated in this document.

Spatial Data Quality

C-CAP standards of data quality are based on authoritative references (Goodchild et al. 1990; Chrisman 1991; Lunetta et al. 1991; Congalton 1991; National Institute of Standards and Technology 1992). These documents recommend that producers of data document:

- **LINEAGE**--A record of the type of data sources and the operations involved in the creation of a database.
- **POSITIONAL ACCURACY AND PRECISION**--The closeness of locational information (in x,y coordinates) to the true position.
- **ATTRIBUTE ACCURACY AND PRECISION**--The closeness of attribute values to their true values.
- **LOGICAL CONSISTENCY**--The adherence of internal data structures to established conventions or stated rules.
- **COMPLETENESS**--The degree to which the data exhaust the universe of possible items.

C-CAP has added to this list:

- **TEMPORAL ACCURACY AND PRECISION**--The time over which source materials were acquired and observations made.

Users are responsible for determining:

- **FITNESS FOR USE**--The degree to which the data quality characteristics of each database and its

components collectively suit an intended application.

The C-CAP protocol also distinguishes between:

- **ACCURACY**--The closeness of results, computations, or estimates to true values (or values accepted to be true)
- **PRECISION**--The number of decimal places or significant digits in a measurement.

The accuracy of the resulting land cover database for each time period and for change between time periods is a crucial measure of the success of C-CAP. Several different types of accuracy are involved, and some of them are difficult to measure. For rigorous statistical measures of accuracy, field-based reference data are exclusively preferred over other data sources including aerial photographs.

Lineage

The sources, scales or resolutions, and dates of materials involved in the preparation of all regional C-CAP databases must be documented (Lunetta et al. 1991), including:

- satellite images or aerial photographs used in the analysis
- aerial photographs (including oblique photographs) used as an aid in training or field verification if the photographs directly influenced identification of land cover types for significant portions of a given area
- collateral information such as National Wetlands Inventory (NWI) data or soils maps if the information directly influenced the identification for significant portions of a given area
- planimetric basemaps
- State and county land cover inventories or other surface level data.

Sources and techniques of georeferencing, especially for submerged land and other land where identifiable features are sparse.

Positional Accuracy and Precision

Positional accuracy is concerned with the accuracy of the geometric placement of points, lines, and polygon boundaries. In land cover databases, polygons are derived either from raster spectral data representing discrete pixels or from closed polygons delineating the edges of spectral signatures in photographs. In the first case, the placement of polygon boundaries depends on (a) spectral signatures selected for class boundaries, and (b) registration of pixel locations. The second case generally applies to the C-CAP SRV projects in which the primary intent is to delineate limits between presence and absence of habitat classes. In this application, polygons of class 1 tend to occur as discrete objects in a large polygon of class 0 which has specified boundaries landward and unspecified boundaries seaward. The placement of polygon boundaries depends on (a) limits of signatures attributed to the habitat class, and (b) registration of horizontal control points present in the base map and visible in the photography. In both cases, signature selection directly affects attribute distribution which, in turn, affects the size and shape of polygons. This effect is most common at polygon edges but may occur throughout the polygon, for example, as internal voids or as circumscribed polygons of different classes. The selection of spectral signatures for class boundaries is similar to the task of generalization that cartographers have traditionally faced in deciding where to draw boundaries between land cover features.

For most remote sensing applications, positional accuracy on the order of + 1 or 2 pixels has not been a

major concern. Neither has positional accuracy for photographic delineations of submersed habitat been a major concern or a subject of independent verification. For a single time period, positional errors may not greatly affect the aggregate area of each land cover type. Positional errors may be difficult to detect even when visiting a specific polygon in the field. For C-CAP, however, positional accuracy is a crucial concern (Ferguson et al. 1992, 1993). The change database amounts to a comparison that will conspicuously record positional errors of one or more pixel dimensions in the satellite imagery and errors in excess of about 10 meters in the photographic images used to delineate submersed habitat. This compounds the problem of recognizing real changes which also tend to concentrate at polygon edges and class boundaries.

The registration of pixel locations is a purely geometric problem which has been greatly improved with recent advances in sensors, global positioning systems (GPS), and image processing systems. Many vendors claim a positional accuracy of + 0.5 root mean square error (RMSE) for commercial image processing systems and a CEP of 3-5 meters for global positioning systems (GPS). Selective availability (SA-- intentional distortion of GPS signals for military security purposes) reduces GPS precision to a CEP of 40 meters when SA is in operation. Differential readings by multiple receivers can improve the quality of positional data, even when SA is active, to a CEP of < 5 meters. C-CAP regional analysts should verify vendor claims to their own satisfaction based on sources of higher precision. Unless stated otherwise, a geometric registration of + 0.5 RMSE will be assumed for all C-CAP regional databases (+ 15 meters if Landsat TM data are used).

For submerged land the registration of polygon edges is a function of the metric quality of photographs, methods used to transfer the information to a planimetric map projection, and quality of the digitization performed. Positional accuracy is therefore subject to the accuracy of the base map including deviations not only between the source photography and the base map but also actual changes in the study area in the intervening time between aerial photography for the base map and for the submersed habitat. A positional accuracy meeting National Map Accuracy Standards is assumed for submersed habitat data. At the compilation scale of 1:24,000 this amounts to + 13.3 meters on the ground, close to the + 15 meter precision of Landsat TM data for uplands and wetlands.

Generalization Versus Error

It is a tribute to the power of modern information technologies that what we used to call generalization, we now call error. With analog maps it has always been necessary to use human judgment in deciding, for example, precisely where a forest becomes a field. In reality most forests have some grass, and most fields have some trees or shrubs. In natural circumstances the boundary is not a precise line but rather a fuzzy zone of highly variable width in which the predominant land cover grades from one class to another. Scale and resolution are crucial determinants of such boundaries. In an analog map, scale places a limit based on the feasibility of drawing the densities and convolutions of lines that would be necessary to represent each patch of forest or each individual tree. Conceptually there will always be unrepresented boundaries because, in the modern sense of fractals, a nearly infinite number of convolutions are possible. Digital systems are capable of representing a much larger portion of all possible boundaries, but there are practical limitations affecting digital systems, as well. In current technology the most often encountered limitation is the established resolution of satellite sensors.

While the terms "error" and "accuracy" are frequently used in regard to generalized boundaries, conceptually the "accurate" boundary can only be determined on the basis of a highly specific set of criteria that goes far beyond what can actually be implemented for large areas. Land cover phenomena are

prime examples of fuzzy sets. This fuzzy characteristic is explicitly recognized in the procedures of image processing (for example, the use of maximum likelihood statistics), but the remote sensing community traditionally has presumed that there is a "right" answer or "ground truth" that can be determined if the analyst can get close enough to see the polygon and its boundary in the field or on the photograph. Yet, different investigators "see" different land covers, especially troublesome when the area is large enough to require multiple teams. In reality, land cover phenomena are fuzzy sets whether viewed directly in the field or through remote sensors. Fuzziness persists because each class is defined, not by a discrete boundary, but by factors that grade from one class to another--spatially, temporally, categorically, and observationally. Also, classification and accuracy assessment procedures are not always implemented in a timely manner, often months or years after the image is collected or analyzed.

Generalization also occurs within delineated polygons whether derived from satellite or photographic images. In both cases a finite limit for signature detection and mapping exists. Minimum detection units are one pixel for spectral scanner data and about one meter for high altitude photographic images. Elimination of "salt and pepper" and reasonable accuracy for perimeter or areal estimates requires a minimum mapping unit of 4 pixels or about 0.4 hectare. At a compilation scale of 1:24,000 the smallest polygon which can be traced from a photograph is about 20 meters in diameter or an effective area on the ground of about 0.03 hectares. Realistically, the goal for improving generalization should be to strive for consistency more than "accuracy", per se.

Reference data for accuracy assessment must have a resolution and reliability which meet or exceed those of the C-CAP remotely sensed data. The reliability, including attribute and positional accuracy, must be demonstrated prior to its qualification as reference data for C-CAP. Reference data, including surface level observations, must be evaluated in accordance with C-CAP's minimum detection unit and minimum mapping unit for the remote data and with the classification system used to categorize the habitat. The presence of a characteristic species or natural or cultural feature may or may not, in itself, establish an area as a particular type of habitat. A number of questions need to be answered to draw a conclusion about the appropriate category of land cover to assign based on the reference data: does a characteristic species or feature meet the minimum detection unit of the remote sensor? what other characteristic species or features also are present within the minimum mapping unit? What conclusion can be drawn from the reference data as to the C-CAP category for a given location based upon data generalized to the minimum detection and minimum mapping units?

Attribute Accuracy and Precision

Attribute accuracy is a measure of the probability that the land cover type for any given polygon is properly identified according to the land cover scheme. For example, if a substantial polygon of "High Intensity Developed" land is identified as "Deciduous Woody Wetland" that is a clear instance of categorical error. If 15% of all sample polygons for this class are misclassified to "Deciduous Woody Wetland" and other categories, the categorical accuracy for the "High Intensity Developed" class is 85%. The remote sensing literature is replete with procedures for measuring attribute accuracy (Congalton 1991). Generally, these procedures serve well for current time periods and for relatively small study areas. Past time periods, however, cannot be field verified. Conventional procedures also are difficult to apply to large areas. Accuracy assessment of large change databases is currently infeasible due to the combination of past time period, large area, and the excessive number of "from" and "to" classes.

Logical Consistency

Tests for logical consistency should indicate that all row and column positions in the selected latitude/longitude window contain data. Conversion, integration, and registration with vector files should indicate that all positions are consistent with earth coordinates. Attribute files must be logically consistent. For example, when examining the change matrix for logical consistency, very few pixels should change from urban to any other category or from water to any category other than bare ground or marsh. The range of appropriate tests is left to the judgment and experience of regional analysts. All attribute classes should be mutually exclusive. The criteria cannot be met if land use classes are included along with land cover classes.

Completeness

The classification scheme should comprehensively include all anticipated land covers. The C-CAP Coastal Land Cover Classification System is intended to provide complete coverage, but it is possible that regional analysts will find special land covers that are not included. It is the responsibility of regional project personnel to ensure that all categories are included, and that all pixels are assigned a category. Regional analysts may use their discretion in deciding at what classification system level (0 to 3) they wish to classify. The level need not be the same for all branches of the classification scheme.

Temporal Accuracy and Precision

Regional analysts should document the time of data collection for the primary input data at least to the precision of year, day, and hour.

Fitness for Use

C-CAP workshops have involved many discussions with potential users and have devoted a great deal of effort to field verification and other types of verification. C-CAP is confident that the databases resulting from compliance with this document will be of sufficient quality to support most activities in the policy and management arenas and some activities in the regulatory and enforcement and research arenas. The spatial precision and attribute accuracy are not sufficient for enforcement of individual small permits, but they may be useful in evaluating cumulative impacts in the vicinity of a permit site or for evaluating individual sites larger than the minimum mapping unit. In the southeast region of the U.S., a vast majority of the total area of coastal salt marsh or seagrass habitat potentially subject to direct loss, according to permits submitted, would be detectable in the C-CAP data (Rivera et al. 1992). They will also be of value in many applications, such as land use planning, unrelated to the C-CAP mission. Ultimately, however, only the user can make the decision regarding fitness for use.

Recommended Accuracy Assessment Test

The recommended accuracy assessment for C-CAP regional databases is a test based on comparison with independent field samples. Independence should be guaranteed through the use of personnel who are not familiar with and do not have access to the results of the land cover classification (Congalton 1991).

Sample Selection and Field Mapping

Regional analysts are responsible for selecting unbiased, statistically meaningful area samples for field verification in the accuracy assessment process.

Accuracy Assessment for Individual Date Classification of Upland and Wetland Habitat Data

Accepted procedures in the remote sensing, cartographic, and geographic literature assess 1) the positional accuracy of identifiable, stable features, and 2) categorical accuracy at the interior of class polygons. Unfortunately, the methods often neglect the fuzzy nature of land cover--categorically (e.g. the class boundary between grass and marsh), spatially (e.g. the polygon boundary between water and marsh), temporally, and observationally. Given these limitations, it is not feasible at this time to provide a quantitative estimate of accuracy with every C-CAP regional database. A reasonable alternative is to establish data quality objectives (DQO) designed to serve expected uses, establish and consistently implement a set of protocols and procedures, and manage the data production process to meet DQOs. C-CAP has conducted three workshops on accuracy assessment and is currently sponsoring two protocol development projects in the hope of devising new procedures that will work for accuracy assessment of large land cover change databases.

Nevertheless, the following material identifies sound procedures that may be used to obtain unbiased field information which, in turn, may be statistically evaluated to perform an accuracy assessment for a single time period. This is a blind field test in which the field mapping personnel will not see the C-CAP Land Cover and Land Cover Change Maps until after all mapping has been completed.

Since the field mapping personnel may be unfamiliar with C-CAP, it is advised that they be required to submit a memorandum stating the design of the field mapping implementation. Early in the effort, regional analysts should review the design, in collaboration with NOAA, and reach agreement with the field mapping personnel regarding final implementation. Field personnel should be provided copies of the land cover classification scheme and trained in its use.

The field personnel will be responsible for ensuring the positional accuracy and precision of each sample site and each land cover class boundary within each site. Field personnel will be responsible for determining physical accessibility and obtaining permission for legal access to the sample sites.

An early determination will be made regarding who is responsible for acquiring the best available aerial photographs, topographic maps, and other collateral data to ensure an accurate mapping of each sample site for each time period. These materials will assist in mapping land cover and land cover change for each site at 1:24,000 scale. Positional accuracy shall comply with national map accuracy standards. The determination of class type will be based primarily on field observation. The determination of class areas and boundaries will be based primarily on aerial photographs. The final results for each sample polygon will be provided in a digital form.

After completion of the field mapping, the regional analysts will compare the generated map for each sample site to the C-CAP map for the same site. All discrepancies will be referred back to the field mapping personnel for a final check. The regional analyst may request a special examination and may accompany the field mapping personnel for a final reconciliation of any discrepancies for which field error is suspected.

The regional analysts will compile the results of all sample polygon comparisons and conduct a statistical analysis. The results of this analysis will be provided to the field mapping personnel for review and comment. At this point the field mapping personnel may also see the C-CAP land cover and land cover change maps for the sample quadrangles.

The field mapping personnel will provide a brief documentation of the field mapping task for inclusion in

the final accuracy assessment report to be prepared by the regional analysts. The field mapping personnel must be given an opportunity to comment on the results of the final statistical analysis if they so choose.

Accuracy Assessment for Individual Date Classification of Water and Submerged Land Data

Accuracy assessment for submersed habitat is similar to that for emergent and upland habitat but it should be noted that data for submersed habitat is intrinsically vector, not raster. Positional and attribute accuracy can both be assessed, positional accuracy of polygon borders and attribute accuracy of a point location. Habitat polygons or areas of potential habitat should be stratified by class and region (water body) and randomly selected. Additional sample locations from potential habitat sites (suitable depth but apparently devoid of habitat) should be randomly selected. Verification locations should be identified by latitude and longitude coordinates and visited in the field with GPS navigation. The nature of the habitat, if present, should be documented by inspection or sampling if necessary and the position of the sample or observation recorded to a CEP of < 5 meters. The entire perimeter of a small polygon or a section, e.g. 0.5 km of the perimeter a large polygon, should be positioned by differentially corrected GPS at a point spacing of 3 to 20 meters depending upon the deviation from linearity in the perimeter. Differential GPS provides CEP of < 5 meters for single position fixes. C-CAP projects generally found that single point differential GPS position fixes did not exceed 10 meters (Ferguson et al. unpublished data). Habitats at the minimum mapping limit, i.e. with diameters on the order of 20 meters, therefore, should be located and delineated with multiple position estimates. GPS manufacturers recommend collection of multiple position fixes for a time period of about 4 minutes to achieve CEP on the order of 1 or 2 meters with differentially collected GPS. Multiple position fixes obtained at strategic points around the perimeter of the smallest mapped polygons would be required to ensure mapping the polygon rather than generating a scattered pattern of points.

Accuracy Assessment for Land Cover Change Data

The methodological difficulties of accuracy assessment for the final change map are significantly greater than those for a single, current database. Remote sensing, cartographic, and geographic literature provide no guidance on techniques for assessing the accuracy of a change detection map (Lunetta et al. 1991; Jensen and Narumalani 1992). Even for a single-time database, existing procedures are ineffective for past land cover since the recommended "source of higher accuracy" cannot include actual field verification. Change detection databases compound the difficulty because they always include a past time period and a large number of "from" and "to" categories (potentially the square of the number of categories for each time). This large change matrix can make accuracy assessment more expensive than the original classification and change detection effort. Furthermore, if the distribution of error is thoroughly depicted by class and position, the accuracy database may be as large as the thematic database itself. Even worse, the distribution of error and the distribution of actual change both tend to concentrate on the same circumstances (for example, polygon edges and transitional classes, such as marsh and palustrine forest). C-CAP is sponsoring workshops to develop improved methods for assessing the accuracy of change databases and maps.

Comparison and Statistical Analysis

The C-CAP land cover database and the field-mapped verification database should be compared and measured to determine differences in attributes for the base time period and for change that can be recognized in the field. The measures obtained from this comparison are numerical differences relating to the sample sites only. It will then be necessary to employ statistical algorithms to determine what the

differences reveal about the accuracy of the entire regional database. These algorithms should be designed to estimate the attribute accuracy and positional accuracy of the change database. The necessary algorithms are not currently available in the remote sensing, cartographic, and geographic literature (Congalton et al. 1991; Jensen and Narumalani 1992). C-CAP is currently funding two protocol development projects in an attempt to remedy this deficiency.

Chapter 6. Product Availability

Digital Product Description

Regional databases generated by C-CAP participants will be provided to the C-CAP Project Director in accordance with procedures specified in research funding proposals (RFP), statements of work (SOW), funding documents, memoranda of agreement (MOU), or other applicable documents under which each Regional Project is authorized and conducted. The purpose of this transfer is to place each regional database into a central archive from which all data will be made available to the public. It will be the responsibility of the regional participants to document and certify that the data have been prepared in accordance with C-CAP protocols. C-CAP may conduct additional data quality and accuracy assessment tests prior to final submission to the archive. The data should adhere to the Spatial Data Transfer Standard (SDTS) proposed by the Federal Geographic Data Committee and adopted as a Federal Information Processing Standard (FIPS) (National Institute of Standards and Technology 1992). Commercial implementations are not currently available, but will be marketed by software vendors in the near future. At a minimum, the standard should be considered a near term goal with one or more defacto standards -- such as DLG, ARC, DXF (geometry only), ERDAS -- accepted in the interim. Lineage, quality, and format information should be transmitted with the data disseminated to users.

The digital product for each region will be a change matrix of land cover by class for coastal submersed habitats, emergent coastal wetlands, and adjacent uplands. The only regional database currently completed and available to the public is the Chesapeake Bay Land Cover Change Database for 1984 and 1988/1989.

Digital Product Availability

The digital products are available from:

[National Oceanographic Data Center](#)

1825 Connecticut Avenue, NW
Washington, DC 20235
(202) 606-4549

When more C-CAP regions have been completed, an on-line electronic catalog will be created for users to browse.

Digital Product Redistribution Restrictions and Disclaimer

Redistribution Restrictions

The product file will contain statements defining the responsibility of the user in regard to C-CAP data. The user must acknowledge NOAA as the source of the product whenever data are redistributed. The user must provide an accounting to NOAA stating who received any copies of the database. If the redistributed data are modified in any way, an accompanying disclaimer must acknowledge NOAA as the source of the original data, must state the nature of the modifications, and must relieve NOAA of responsibility for the modified data.

Liability Disclaimer

The user of C-CAP data will hold the U.S. Government and its agencies, officers and employees harmless against any and all liability, including costs and expenses, which may result from or arise out of any use of the data.

Digital Product Format and Contents

The goal is to exchange the digital products in the Federal Spatial Data Transfer Standard (SDTS) format for raster data. Until the SDTS raster standard is available, the initial data products may not adhere to the final standard.

Product Identifiers and Characteristics

Each data transmittal from NODC to the user will be accompanied by documentation provided by the data producers stating the following:

- Geographical coverage in UTM coordinates
- UTM zone number
- Computer and operating systems used to create the file
- Precision of the computer system (e.g. 16-bit; 32-bit)
- Software used to create the file (e.g. ERDAS Imagine 8.2; ARC-Info 7.0)
- Type of file (ASCII, binary, ERDAS.IMG, ARC-Info coverage)
- Description and format of header file
- Data Record Format
- Number of classes
- Class names
- Number of pixels by class and by file, including the null class (no data in pixel)

The header file for each database will repeat the quantitative portion of this information.

Product Data Quality

The documentation will describe the lineage, date and source of data (i.e., instrument, platform), resolution, positional accuracy and precision, attribute accuracy and precision, logical consistency, completeness, and temporal accuracy and precision of the data being transferred.

Guidance Version

The product file will contain a field indicating the C-CAP Guidance for Regional Implementation version used to produce the image product. The current version is 1.0.

Transfer Verification Parameters

Each C-CAP product will contain unique verification parameters for the image raster data and a confirmation algorithm that can be applied to the image values. The algorithm tests whether the database received by the user is equivalent to the original. If an image has been damaged or modified, application of the algorithm will produce results different from the master values in the original data file maintained at the NODC. The occurrence of each class value (including the no data class) can be tabulated and compared with the original summary statistics.

Derived Data and Quality

The data product may include derived data, such as tabular summaries of land cover and accuracy assessments for specified areas (e.g. counties, watersheds, wildlife management areas). Data are defined as "derived data" if they cannot be used to reconstitute the C-CAP data at the pixel level.

Digital Data Values

The data values in raster format are numerical values representing the land cover categories described in this document (see ["The C-CAP Coastal Land Cover Classification System"](#)). A lookup table or other accompanying statement will define the relationship between the stored values and the land cover categories.

Digital Product Medium

Digital data products will be available on 9-track magnetic tapes. As the completed coverage expands, these data may be available on other magnetic and optical media such as CD-ROM.

Digital Product Cost

The organization conducting each regional project will receive one copy of the final database as distributed by NODC at no cost. All other users will be charged the standard NODC cost of reproduction fee.

Digital Product Ancillary Documentation

General Protocol

A copy of the C-CAP Guidance for Regional Implementation for the version used to produce the product will be available from the NODC in digital form for the cost of reproduction.

Specific Digital Products Documentation

Regional analysts may provide ancillary documentation for dissemination by NODC if both the documentation and the corresponding database are provided to NODC in a standard digital format.

Hardcopy Products

Upland and Wetland Habitats

Hardcopy maps of uplands and wetlands for selected areas will be produced for informational purposes, primarily to illustrate database content. At present there are no plans to publish hardcopy maps for general sales and distribution to the public. Requests for informational maps will be considered on a case by case basis.

Individuals and organizations should make their requests in writing to:

Dr. Ford A Cross, Director
NOAA/National Marine Fisheries Service
Beaufort Laboratory
101 Pivers Island Road
Beaufort, NC 28516-9722

Organizations wishing to serve as value-added vendors of hardcopy products derived from C-CAP data should write to this address.

Submersed Habitats

Hardcopy maps are routinely produced as part of the submersed habitat change analysis because the techniques are currently based on aerial photographic interpretation in analog form. A limited number of publication-quality maps are reproduced at the completion of each regional task. Individuals and organizations may request copies on a "first come, first served" basis by writing to Dr. Ford A Cross at the address listed above.

Chapter 7. Users and Information Needs

Table 6. presents a matrix developed by participants in the regional concerns breakout group at the C-CAP Rhode Island Workshop (see Appendix 4). The matrix matches potential uses with C-CAP products and indicates the relative value of the product according to use. Interested parties are encouraged to modify this table from their own regional perspective and submit their modifications to C-CAP. This will enable C-CAP to generate matrices for each region or a single national matrix that will help ensure that C-CAP products meet the broadest range of user needs possible.

Table 6. The potential utility of C-CAP coastal land-cover information: H=high M=moderate L=low.

Potential Uses:	Map data	Digital Data	Tables	Physical Boundaries	Error Estimation
Technical review	M	M	L	L	L
Modeling	M	M	L	L	L
Interstate Coordination	L	H	H	H	H
Enforcement	H	H	H	H	H
Hazard Response	H	H	L	L	L

Policy	L	L	H	H	H
Management/Planning	H	H	H	H	H
Education	H	H	M	M	H
Citizens	H	L	L	L	L
Commerce	H	H	L	L	H
Research	H	H	M	M	H

Chapter 8. Regional Participation

Purpose

NOAA C-CAP will endeavor to cooperate with all ongoing wetlands mapping and change detection programs at the federal, state, and regional levels. Priorities for NOAA funding allocation will be:

- 1. biogeographic diversity
- 2. joint funding efforts
- 3. existing field-based studies

Other considerations will include:

- 1. areas of rapid development
- 2. areas disturbed by major storms or other natural events
- 3. areas disturbed by hazardous technologies (e.g., oil spills)

Regional Project Summaries

St. Croix River Estuary (Border of Maine and New Brunswick, Canada)

This is a cooperative effort involving the U.S. Fish and Wildlife Service, the Gulf of Maine Program, and Environment Canada. A change detection analysis is being performed using TM imagery from 1985 and 1992. The image processing and change detection analysis is being performed at ORNL. Five field verification exercises have been carried out in conjunction with U.S. Fish and Wildlife Service personnel. A final C-CAP change detection product is expected in the fall of 1992.

Coastal Massachusetts

This is a cooperative SAV effort involving the Massachusetts Department of Environmental Protection, Wetlands Conservancy Program. A pilot project focusing on training Massachusetts personnel in current SAV mapping techniques and adapting the C-CAP protocol to use in Massachusetts was conducted in the spring and summer of 1993. Photointerpretation and mapping are being performed by DEP personnel with technical assistance from the NMFS Beaufort Laboratory. The SRV polygons will be added to wetland data on coastal orthophoto maps.

Universities of Connecticut and Rhode Island

Faculty of the Universities of Connecticut and Rhode Island are working cooperatively to examine several issues concerning coastal land cover classification and change detection in the Northeast (Hurd et al. 1992). In the first part of the project, detailed GIS data on coastal wetlands in Rhode Island derived from aerial photography were used to establish coastal wetlands signatures for input to a digital classification of Landsat TM imagery. This work is crucial in assessing the extent to which an existing coastal wetlands data set (e.g. NWI digital data) can be used to establish a classification for a larger TM data set. Other areas of importance to the C-CAP project include assessments of: 1) classification approaches best suited to characterize wetlands in southern New England; 2) techniques for monitoring coastal wetlands change in the Northeast using several change detection techniques to look at TM imagery from the same location for 1988 and 1982; and 3) multi-state, multi-institutional collaboration in southern New England.

University of Delaware

University of Delaware faculty played a lead role in development of the interagency land cover classification system used by C-CAP (Klemas et al. 1993). The system was developed during joint meetings with representatives from key government agencies including NOAA, USGS, EPA, USFWS, and COE.

Currently University of Delaware faculty are developing remote sensing and field techniques for measuring indicators of wetland condition and functional health over large wetland areas. An overview of wetland health assessment techniques has been prepared, with special emphasis on wetland condition and functional health indicators that can be monitored with remote sensors (Patience and Klemas 1993). The overview report contains a comprehensive literature search and chapters describing the techniques and their status. A joint study has been initiated with investigators from Louisiana State University and EPA to work on impaired and healthy pilot test sites in Louisiana marshes. Field data, including measures of biomass, soils, hydrology, chemistry, biology, and light reflectance are being correlated with Landsat TM imagery to assess biomass and stress indicators over large areas with the help of modified models and techniques developed during previous studies. The data derived from these investigations are crucial to C-CAP for early detection of functional change in habitat.

Oak Ridge National Laboratory

The C-CAP prototype and first regional project was conducted in the Chesapeake Bay Region by ORNL (Dobson and Bright 1991, 1992, 1993). In the first phase a land cover classification was completed for a four-scene area using MSS data for October 24-25, 1978, and change detection was completed for portions of a scene in the vicinity of Metomkin Inlet, VA, using MSS data for September 12, 1974, MSS data for October 24, 1978, and TM data for November 18, 1982. The Virginia Institute of Marine Sciences (VIMS) was contracted to assist in field verification and training sample identification. The results of this prototype served as a proof-of-principle for large-area change analysis and the methods and techniques served as the basis for the draft protocol presented at the first protocol development workshop.

This initial prototype and proof-of-principle was conducted at the Oak Ridge Geographics Laboratory. All cartographic and geographic information processing was conducted by ORNL personnel using Oak Ridge Geographics software. Tentative land cover classes were determined on the basis of supervised training samples in areas of known land cover. The tentative classes were checked with information available from other sources such as 1:24,000 USGS topographic maps and with additional information

available from wetlands inventories (NWI and county marsh inventories). Investigators visited the area on November 4-6, 1985 for field verification of the tentative classes and for identification of additional training samples in the Wachapreague, Metomkin Inlet, and Saxis areas of Virginia. Land cover classes were determined through iterative refinement of supervised training samples. Investigators visited the area in August 1986 for field verification of final land cover classes in the York River Estuary of Virginia and the Tangier Island and Blackwater National Wildlife Refuge areas of Maryland. Finally, the entire data set was compared digitally on a cell by cell basis to land cover data from the USGS Land Use Data Analysis (LUDA) database in order to resolve certain classes.

In the second phase the change detection was extended to cover the full four-scene area using TM data for August 27, 1984 and September 21, 1984 and TM data for November 3, 1988 and October 10, 1989. The final product consisted of a classified land cover change matrix database for the entire Chesapeake Bay Area. Regional maps at 1:500,000 scale and numerous local area maps covering individual USGS 1:100,000 and 1:24,000 quadrangle areas were prepared to illustrate static land cover for 1984 and 1988/1989 and land cover change between these dates. The final database was delivered to NODC and is available for purchase by the public. This analysis was conducted on graphics workstations employing ERDAS image processing software, ERDAS raster GIS software, and Oak Ridge Geographics GIS software. Processing and verification techniques were similar to those employed in the initial MSS/TM analysis. Investigators revisited the area in the Spring and Summer of 1991, and participated in the Maryland field verification workshop (See Appendix 4). Finally, the database was modified to accommodate the new C-CAP land cover classification scheme and to incorporate suggestions and corrections resulting from the Maryland workshop. The protocols developed for the Chesapeake Bay Project have been incorporated into the C-CAP protocols. The final C-CAP Chesapeake Bay Land Cover Change Database, thus, complies with this document. The database is available, at cost of reproduction, from NOAA's National Oceanographic Data Center (See [Chapter 6](#)).

Virginia Institute of Marine Sciences

The Virginia Institute of Marine Sciences has been conducting photographic mapping of submersed vegetation in the entire Chesapeake Bay beginning in 1978 and annually since 1984 (Orth et al. 1990, 1991). Although not funded by C-CAP this important work is considered a regional C-CAP project due to voluntary collaboration among principal investigators. Methodology for the Chesapeake Bay Project was a starting point for the C-CAP protocol. Data from Chesapeake Bay has been provided to C-CAP to attempt an overlay of it with the land cover data for Chesapeake Bay generated by ORNL. Historically, Chesapeake Bay has suffered a dramatic decline in SAV and associated fisheries. From 1984 to 1990, however, SAV habitat increased from 15,400 to 24,313 ha.

North Carolina State University

A land cover classification project was conducted by the Computer Graphics Center at North Carolina State University (NCSU) prior to the university's involvement in C-CAP. Coincidentally the four-scene area analyzed by NCSU was contiguous with the four-scene area analyzed by Oak Ridge National Laboratory (ORNL) in the Chesapeake Bay Project. Scene dates are contemporaneous with the 1988 Chesapeake Bay scenes. NCSU faculty cooperated with ORNL research staff to investigate the potential for merging portions of these two independently conducted land cover classifications based on TM digital data. The goal was to merge the project areas and form a seamless regional land cover classification from the Chesapeake Bay to Dare County, NC. One of the major problems investigated was the development

of a classification scheme adaptable to both areas. This research was a crucial test of the C-CAP concept of regional compatibility among neighboring databases developed by different organizations.

Beaufort Laboratory, National Marine Fisheries Service

This project in North Carolina is researching protocol for conducting and verifying change detection in SRV, including seagrasses and low salinity-tolerant grasses and forbs. Simultaneously the project is completing the first comprehensive inventory of such habitat in North Carolina. The project was jointly funded by the Albemarle Pamlico Program of EPA's National Estuary Program since.

All aerial photography from 1985 through 1991 were interpreted and most compiled on base maps. The interpretation was supported by extensive systematic and directed sampling throughout the study area. At the time of photography, stations were systematically selected, visited and sampled for species of submersed plants and ancillary data (sediment particle size and organic content, water depth, salinity, temperature, Secchi depth and presence of exposed peat deposits, shells, algae or debris which might confuse signature identification). All locations of known and potential habitat, water < 6 feet at mean lower low water on nautical charts, were sampled by positioning a rectangular matrix of points over the nautical chart. Station positions approximately 2 scaled nautical miles apart were extracted from the chart and visited with the aid of LORAN C, now, preferably, GPS. Subsequent to receipt and preliminary interpretation of the photographs, field surveys were conducted to verify the range of habitat signatures and confirm false signatures.

Photographs initially interpreted monoscopically are now interpreted stereoscopically. Polygons are traced on stable film at the photograph scale and rectified and transferred to base maps using a zoom transfer scope. Base maps are NOAA shoreline manuscripts, if available, or USGS 7.5 minute topographic series maps, if consistent with current photographs, on stable media. The topographic maps are virtually complete for North Carolina (with the exception of Currituck Sound) but are out of date (mid-forties photography with occasional photo-revision for cultural features dated in the seventies or eighties). NOAA shoreline manuscripts are based on 1988 or more recent photography but are not complete for North Carolina. Necessary photographs for construction of manuscripts to complete shorelines in North Carolina were obtained in the period 1988 through 1992.

Habitat polygons were coordinate digitized by the State of North Carolina personnel and incorporated into a state-wide ARC-Info database referenced to the State Plane Coordinate System. Three 2-color charts of seagrass habitat at a scale of 1:36,000 and measuring about 3' by 4' were published and are available at no cost.

University of South Carolina

University of South Carolina faculty performed a detailed investigation of the geographic area centered on two 7.5' U.S. geological Survey quadrangles along South Carolina's coastal plain. These quads, representative of many other quads in coastal South Carolina, provide an opportunity to examine two very different wetland communities. One quad is directly on the coast and contains extensive *Spartina alterniflora* marsh, developed and undeveloped beach front, and a mature maritime forest. The other quad is 40 river miles inland and contains significant inland freshwater wetlands with extensive bottomland hardwoods. The project identified optimum parameters for conducting accurate coastal change detection including, but not limited to: 1) optimum wetlands classification scheme; 2) optimum type of remotely sensed data; 3) optimum digital image processing pattern recognition algorithms for C-CAP land cover

classification; 4) applicability and utility of including ancillary data (e.g. NWI digital data) in the classification process; 5) optimum change detection algorithm logic; and 6) detailed error evaluation. Results were reported in Jensen et al. (1993a)

The State of Florida Department of Environmental Protection

State of Florida personnel are mapping submersed habitat in the Florida Keys, Florida Bay, Biscayne Bay and Tampa Bay. Photography were collected in the winter of 1991, 1992 by the NOAA Photogrammetry Branch. The effort in the Keys is cooperative with NOAA's Marine Sanctuary Program. The Keys were photographed at 1:48,000 due to cost considerations and will be a demonstration of resolution of signatures of submersed habitat at a scale smaller than acceptable with the current C-CAP protocol. The motion compensating camera used in this case should enhance resolution. Photography in Florida Bay is being interpreted and ground verified in FY93. C-CAP is partially funding the cost of photography and interpretation.

Texas Parks and Wildlife Department

This agency is currently performing a change detection analysis for a two TM scene area in the Galveston (Christmas) Bay area. The change analysis is being done by TPWD personnel with technical assistance from ORNL. Two scenes for 12/2/88 have already been classified, and a change detection analysis is being performed, comparing a November 1992 scene to the southernmost of the 1988 scenes. Classification has been aided by an abundance of ground reference data, and digital NWI data that is available for most of the Texas coast.

Columbia River, Tillamook Bay and Willapa Bay (Oregon and Washington)

This is a cooperative effort involving the cooperating agencies within the Columbia River Estuary Study Taskforce (CREST), the NMFS/Point Adams Field Station, Hammond, OR, and Washington state personnel. Imagery for September of 1989 and 1992 has been obtained and a change detection analysis is being performed by Crest and its cooperators in conjunction with ORNL. Several field verification exercises have been performed, and a final change detection product is expected in the fall of 1994. This information should be useful to a variety of managers that are presently dealing with severely stressed salmon stocks throughout the study area.

The Hubbard Glacier and Russell Fiord, Alaska.

This is a cooperative effort involving NMFS's Auke Bay Laboratory. A 1986 image is the only image available at this time that meets C-CAP cloud cover specifications. The implications of the future movements of the Hubbard Glacier make this project unique. During 1986 the Hubbard Glacier blocked off the mouth of the Russell Fiord, creating the worlds largest glacier-formed lake. Within months, rising water levels caused the glacier to burst, restoring tidal flow to the Fiord. Glacier experts predict that there is a 90% chance that the Hubbard Glacier will block off the mouth of the Russell Fiord again within the next ten years. Since the portion of the glacier that will block off the Fiord is bigger than in 1986, it is predicted that the glacier will not burst. This would cause the rising waters to exit the Fiord at the end opposite the cglacier, flowing into the Old Situk Creek. This could cause significant impacts to a very important salmon fishery, crucial to the inhabitants of nearby Yakutat. AK. C-CAP is presently looking for another image to perform a change analysis and provide more baseline information for future change detection activities, should the glacier again close off Russell Fiord. The image processing is being

performed at ORNL.

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References

- Anderson J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geol. Surv. Prof. Pap. 964.
- Armstrong, R. A. 1993. Remote sensing of submerged vegetation canopies for biomass estimation. *Int. J. of Remote Sensing* 14:621-627.
- Augenstein, E. W., D. A. Stow, and A. S. Hope. 1991. Evaluation of SPOT HRV-XS data for kelp resource inventories. *Photogramm. Eng. Remote Sensing* 57:501-509.
- Baker, J. R., S. A. Briggs, V. Gordon, A. R. Jones, J. J. Settle, J. R. Townshend, and B. K. Wyatt. 1991. Advances in classification for land cover mapping using SPOT HRV imagery. *Int. J. of Remote Sensing* 12:1071-1085.
- Bartlett, D. S. 1987. Remote sensing of tidal wetlands. In *Remote sensing of estuaries, proceedings of a workshop*, Washington, D.C. (V. V. Klemas, J. P. Thomas, and J. B. Zaitzeff, eds.), U.S. Dep. Comm., NOAA. p. 145- 156.
- Bormann, F. H., and G. E. Likens. 1969. The watershed-ecosystem concept and studies of nutrient cycles. In *The ecosystem concept in natural resource management*, (G. M. VanDyne, ed.), p. 49-67, Academic Press, New York.
- Campbell, J. B. 1987. *Introduction to remote sensing*. Guilford Press, New York.
- Caspers, H. 1967. Estuaries: analysis of definitions and biological considerations. In *Estuaries* (G.H. Lauff, ed.), p. 6-8, Am. Assoc. Adv. Sci. Publ. 83.

- Cheng, T. D., G. L. Angelici, R. E. Slye, and M. Ma. 1992. Interactive boundary delineation of agricultural lands using graphics workstations. *Photogramm. Eng. Remote Sensing* 58:1439-1443.
- Chrisman, N. R. 1991. The error component in spatial data. In *Geographical information systems: principles and applications*. (D. J. Maguire, M. F. Goodchild, and D. W. Rhind, eds.), Wiley, New York.
- Chuvieco, E., and R. G. Congalton. 1988. Using cluster analysis to improve the selection of training statistics in classifying remotely sensed data. *Photogramm. Eng. Remote Sensing* 54:1275-1281.
- Clark, J. A., and J. A. Primus. 1990. Sea-level changes resulting from future retreat of ice sheets: an effect of CO₂ warming of the climate. In *Sea-level changes* (M. J. Tooley, and I. Shennan, eds.), p. 356-370. Blackwell, Oxford.
- Congalton, R. G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environ.* 37:35-46.
- Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildl. Serv. FWS/OBS-79/31.
- Cowen, D. J., J. R. Jensen, and J. Halls. 1991. Maintenance of TIGER Files using remotely sensed data. *Am. Soc. Photogramm. Remote Sensing* 4:31-40.
- Cross, F. A., and J. P. Thomas. 1992. CoastWatch Change Analysis Program (C-CAP): an overview Chesapeake Bay regional project. In *Global change and education*, Vol. 1, p. 57. American Society for Photogrammetry and Remote Sensing, ASPRS/ACSM 92 Tech. Pap., Bethesda, MD.
- Crowell, M., S. P. Leatherman, and M. K. Buckley. 1991. Historical shoreline change: error analysis and mapping accuracy. *J. Coastal Res.* 7:839-852.
- Dahl, T. W. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Fish & Wildlife Service, Washington, D.C.
- Daiber, F. C. 1986. Conservation of tidal marshes. Van Nostrand Reinhold, New York.
- Den Hartog, C. 1970. The seagrasses of the world. North Holland, Amsterdam.
- Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, P. W. Bergstrom, and R. A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation: habitat requirements as barometers of Chesapeake Bay health. *Bio Science* 43(2):86-94.
- Dobson, J. E. 1993a. Land cover, land use differences distinct. *GIS World* 6(2):20-22.
- Dobson, J. E. 1993b. A conceptual framework for integrating remote sensing, GIS, and geography. *Photogramm. Eng. Remote Sensing* (In Press).
- Dobson, J. E., and E. A. Bright. 1991. CoastWatch--detecting change in coastal wetlands. *Geo Info Systems* (Jan.), 36-40.
- Dobson, J. E., and E. A. Bright. 1992. CoastWatch Change Analysis Program (C-CAP) Chesapeake Bay regional project. In *Global change and education*, Vol. 1, p. 109-110. American Society for Photogrammetry and Remote Sensing, ASPRS/ACSM 92 Tech. Pap., Bethesda, MD.
- Dobson, J. E., and E. A. Bright. 1993. Large-area change analysis: The CoastWatch Change Analysis

Project (C-CAP). Proceedings of The Pecora 12 Conference (In Press).

Eastman, J. R., and M. Fulk. 1993. Long sequence time series evaluation using standardized principal components. *Photogramm. Eng. Remote Sensing* 59:991- 996.

Eckhardt, D. W., J. P. Verdin, and G. R. Lyford. 1990. Automated update of an irrigated lands GIS using SPOT HRV imagery. *Photogramm. Eng. Remote Sensing* 56:1515-1522.

Ellis, M. 1978. Coastal mapping handbook. U.S. Government Printing Office. Washington, D.C.

Federal Geodetic Control Committee. 1984. Standards and specifications for geodetic control networks. NOAA, National Geodetic Information Branch, N/CG17X2, Sect. 2, p. 1.

Ferguson, R. L., G. W. Thayer, and T. R. Rice. 1980. Marine primary producers, functional adaptation of marine organisms. (F. J. Vernberg and W. Vernberg, eds.), p. 9-69. Academic Press, New York.

Ferguson, R. L., and L. L. Wood. 1990. Mapping submerged aquatic vegetation in North Carolina with conventional aerial photography. In federal coastal wetland mapping programs, (S. J. Kiraly, F. A. Cross and J. D. Buffington, eds), p. 125-133. U.S. Fish Wild. Serv. Biol. Rep. 90 (18).

Ferguson, R. L., L. L. Wood, and D. B. Graham. 1992. Detection of change in submerged coastal habitat. In *Global change and education*, Vol. 1, p. 70-79. American Society for Photogrammetry and Remote Sensing, ASPRS/ACSM 92 Tech. Pap., Bethesda, MD.

Ferguson, R. L., L. L. Wood, and D. B. Graham. 1993. Monitoring spatial change in seagrass habitat with aerial photography. *Photogramm. Eng. Remote Sensing* 59:1033-1038.

Foody, G. M., N. A. Campbell, N. M. Trodd, and T. F. Wood. 1992. Derivation and applications of probabilistic measures of class membership from the maximum- likelihood classification. *Photogramm. Eng. Remote Sensing* 58:1335-1341.

Fung, T. and E. LeDrew. 1987. Application of principal components analysis for change detection. *Photogramm. Eng. Remote Sensing* 53:1649-1658.

Gong, P., and P. J. Howarth. 1990. An assessment of some factors influencing multispectral land-cover classification. *Photogramm. Eng. Remote Sensing* 56:597-603.

Goodchild, M. F., and K. K. Kemp (eds.). 1990. Technical issues in GIS: NCGIA core curriculum. National Center for Geographic Information and Analysis, Santa Barbara. 3vols.

Fung, T., and E. LeDrew. 1988. The determination of optimal threshold levels for change detection using various accuracy indices. *Photogramm. Eng. Remote Sensing* 54:1449-1454.

Haddad, K. D., 1992. CoastWatch Change Analysis Program (C-CAP) remote sensing and GIS protocols. In *Global change and education*, Vol. 1, p. 58-69. American Society for Photogrammetry and Remote Sensing, ASPRS/ACSM 92 Tech. Pap., Bethesda, MD.

Haddad, K. D., and D. R. Ekberg. 1987. Potential of Landsat TM imagery for assessing the national status and trends of coastal wetlands. In *Coastal Zone '87*, (O. Magoon, H. Converse, D. Miner, L. Tobin, D. Clark and G. Dormurat, eds.), p. 5182-5195. American Society of Civil Engineers, New York, Vol. 5.

Haddad, K. D., and B. A. Harris. 1985. Use of remote sensing to assess estuarine habitats. In *Coastal Zone '85*, (O. Magoon, H. Converse, D. Miner, D. Clark and L. Tobin, eds.), American Society of Civil

Engineers, New York.

Haddad, K. D., and G. McGarry. 1989. Basin-wide management: a remote sensing/GIS approach. In Coastal Zone '89, (O. Magoon, H. Converse, D. Miner, L. Tobin and D. Clark, eds.), Vol. 2, p. 1822-1836. American Society of Civil Engineers, New York.

Hodgson, M. E., and R. W. Plews. 1989. N-dimensional display of cluster means in feature space. *Photogramm. Eng. Remote Sensing* 55:613-619.

Hurd, J. D., Civco, D. L., LaBash, C. L. and P. V. August. 1992. Coastal wetland mapping and change detection in the northeastern United States. In *Global change and education*, Vol. 1, p. 130-139. American Society for Photogrammetry and Remote Sensing, ASPRS/ACSM 92 Tech. Pap., Bethesda, MD.

Jensen, J. R. 1986. *Introductory digital image processing: a remote sensing perspective*. Englewood Cliffs, N.J., Prentice-Hall.

Jensen, J. R. 1994. *Introductory digital image processing: a remote sensing perspective*. 2nd ed., Englewood Cliffs, N.J., Prentice-Hall. (In Press)

Jensen, J. R., D. J. Cowen, S. Narumalani, J. D. Althausen, and O. Weatherbee. 1993a. An evaluation of CoastWatch change detection protocol in South Carolina. *Photogramm. Eng. Remote Sensing* 59:1039-1046.

Jensen, J. R., D. J. Cowen, O. Weatherbee, J. D. Althausen, S. Narumalani, B. J. Kjerfve, P. Talwani, and R. Lacy. 1992. Change detection algorithm evaluation: CoastWatch protocol development in South Carolina. In *Global change and education*, Vol. 1, p. 120-129. American Society for Photogrammetry and Remote Sensing, ASPRS/ACSM 92 Tech. Pap., Bethesda, MD.

Jensen, J. R. and S. Narumalani. 1992. Improved remote sensing and GIS reliability diagrams, image genealogy diagrams, and thematic map legends to enhance communication. *Int. and Remote Sensing* 6(B6):125-132.

Jensen, J. R., S. Narumalani, O. Weatherbee, and H. E. Mackey. 1993b. Measurement of seasonal and yearly cattail and waterlily changes using multirate SPOT panchromatic data. *Photogramm. Eng. Remote Sensing* 59:519-525.

Jensen, J. R., E. W. Ramsey, J. M. Holmes, J. E. Michel, B. Savitsky, and B. A. Davis. 1990. Environmental sensitivity index (ESI) mapping for oil spills using remote sensing and geographic information system technology. *Int. J. Geographical Information Systems* 4:181-201.

Jensen, J. R., E. W. Ramsey, H. E. Mackey, E. Christensen, and R. Sharitz. 1987. Inland wetland change detection using aircraft MSS data. *Photogramm. Eng. Remote Sensing* 53:521-529.

Jensen, J. R., L. Tinney, and J. Estes. 1980. Remote sensing techniques for kelp surveys. *Photogramm. Eng. Remote Sensing* 46:743-755.

Kean, T. H., C. Campbell, B. Gardner, and W. K. Reilly. 1988. *Protecting America's wetlands: an action agenda*, Final Report of the National Wetlands Policy Forum. The Conservation Foundation, Washington, D.C.

Keller, M. 1978. A study of applied photogrammetric bathymetry in the National Oceanic and Atmospheric Administration. In *Coastal Mapping Symposium, Proceedings*, p. 45-54. American Society

of Photogrammetry, Falls Church, Va.

Kenworthy, W. J., and D. E. Haunert, (eds.). 1991. The light requirements of seagrasses. NOAA Tech. Memo. NMFS-SEFSC-287.

Khorram, S., J. A. Brockhaus, and H. Cheshire. 1992. Merger of independently derived wetland inventory data bases. In *Global change and education*, Vol. 1, p. 111-119. American Society for Photogrammetry and Remote Sensing, ASPRS/ACSM 92 Tech. Pap., Bethesda, MD.

Kiraly S. J., F. A. Cross, and J. D. Buffington (eds.). 1990. Overview and recommendations. In *federal coastal wetland mapping programs*, (S. J. Kiraly, F. A. Cross and J. D. Buffington, eds), p. 1-7. U.S. Fish Wild. Serv. Biol. Rep. 90 (18).

Klemas, V., J. E. Dobson, R. L. Ferguson, and K. D. Haddad. 1993. A coastal land cover classification system for the NOAA CoastWatch Change Analysis Project. *J. Coastal Res.* 9:862-872.

Klemas, V., and M. A. Hardisky. 1987. Remote sensing of estuaries: an overview. *Remote Sensing of Estuaries*. (V. Klemas, J. P. Thomas, and J. B. Zaitzeff, eds.) p. 91-120. National Oceanic and Atmospheric Administration, Washington, D. C.

Lacy, R. 1992. South Carolina finds economical way to update digital road data. *GIS World* 5:58-60.

Lade, P. K., D. Case, J. French, and H. Reed. 1988. Delineation and classification of submerged aquatic vegetation using SPOT satellite multispectral digital data. Final Report to the Maryland Dept. Natural Resources, Tidewater Administration, Coastal Resources Div., Annapolis, Md.

Lee, J. K., R. A. Park, and P. W. Mausel. 1992. Application of geoprocessing and simulation modeling to estimate impacts of sea level rise on the northeast coast of Florida. *Photogramm. Eng. Remote Sensing* 58:1579-1586

Light, D. 1993. The National Aerial Photography Program as a geographic information system resource. *Photogramm. Eng. Remote Sensing* 59:61-65.

Luczkovich, J. J., T. W. Wagner, J. L. Michalek, R. W. Stoffle. 1993. Discrimination of coral reefs, seagrass meadows, and sand bottom types from space: a Dominican Republic case study. *Photogramm. Eng. Remote Sensing* 59:385-389.

Lunetta, R. S., R. G. Congalton, L. K. Fenstermaker, J. R. Jensen, K. C. McGwire, and L. R. Tinney. 1991. Remote sensing and geographic information system data integration: error sources and research issues. *Photogramm. Eng. Remote Sensing* 57:677-687.

Mausel, P. W., W. J. Kramber, and J. K. Lee. 1990. Optimum band selection for supervised classification of multispectral data. *Photogramm. Eng. Remote Sensing* 56:55-60.

Narumalani, S., J. R. Jensen, M. Hayes, J. Michel, T. Montello, and J. Robinson. 1993. *Geo Info Systems* 3(6):33-41.

National Institute of Standards and Technology (NIST). 1992. Spatial data transfer standard. FIPS Publication 173, Springfield, VA, National Technical Information Service.

NOAA Photogrammetry Branch. 1980. Standard operating procedures for Flight Operations Group of the Photographic Operations Section. NOAA, Rockville, Md.

NOAA Photogrammetry Branch. 1989. Coastal mapping program operations manual. Section 3, Quality Program, NOAA, Rockville, Md.

Novak, K. 1992. Rectification of digital imagery. *Photogramm. Eng. Remote Sensing*, 58:339-344.

Odum, E. P. 1971. *Fundamentals of ecology*. W. B. Saunders, Philadelphia, Pa.

Office of Management and Budget. 1990. Coordination of surveying, mapping, and related spatial data. Circular A-16, Executive Office of the President, Washington, D.C.

Omernick. 1987. *Ecoregions of the United States*. EPA Environmental Research Lab., Corvallis, OR, EPA/600/D-87/.

Orth, R. J., and K. A. Moore. 1983. Submerged vascular plants: techniques for analyzing their distribution and abundance. *J. Mar. Tech. Soc.* 17:38-52.

Orth, R. J., K. A. Moore, and J. E. Nowak. 1990. Monitoring seagrass distribution and abundance patterns: a case study from the Chesapeake Bay. In *federal coastal wetland mapping programs*, (S. J. Kiraly, F. A. Cross and J. D. Buffington, eds), p. 111-123. U.S. Fish Wild. Serv. Biol. Rep. 90 (18).

Orth, R. J., R. L. Ferguson, and K. D. Haddad. 1991. Monitoring seagrass distribution and abundance patterns. *Coastal Wetlands Coastal Zone '91 Conference*, Long Beach, American Society of Civil Engineers, p. 281-300.

Patience, N. and V. V. Klemas. 1993. Wetland functional health assessment using remote sensing and other techniques: literature search. NOAA Tech. Memo. NMFS-SEFSC-319.

Patterson, S. G. 1986. Mangrove community boundary interpretation and detection of areal changes on Marco Island, Florida: application of digital image processing and remote sensing techniques. U.S. Fish Wild. Serv., Biol. Rep. 86(10):1-87.

Phillips, R. C. 1974. Temperate grass flats. In *Coastal ecological systems of the United States*. Vol. 2, (H. T. Odum, B. J. Copeland, and E. A. McMahan, eds.), p. 244-314. The Conservation Foundation, Washington, D.C.

Phillips, R. C. 1984. The ecology of eelgrass meadows in the Pacific Northwest: a community profile. U.S. Fish and Wildlife Service, FWS/OBS-84/24, p. 85.

Price, K. P., D. A. Pyke, and L. Mendes. 1992. Shrub dieback in a semiarid ecosystem: the integration of remote sensing and GIS for detecting vegetation change. *Photogramm. Eng. Remote Sensing* 58:455-463.

Rivera, J. A., A. Mager, Jr., R. L. Ferguson, D. W. Field, and F. A. Cross. 1992. Verification of submerged aquatic vegetation alterations associated with Corps of Engineers permit requests. *Proceedings of the First Thematic Conference on Remote Sensing for Marine and Coastal Environments*, New Orleans, La., 15-17 June, 1992, p. 781-794.

Rutchev, K. and L. Velcheck. 1993. Development of an everglades vegetation map using a SPOT image and the Global Positioning System. *Photogramm. Eng. Remote Sensing* (in press).

Ryerson, R. 1989. Image interpretation concerns for the 1990s and lessons from the past. *Photogramm. Eng. Remote Sensing* 55:1427-1430.

Slamma, C. C. 1980. Manual of photogrammetry, 4th Ed. American Society of Photogrammetry, Falls Church, Va, 1056 p.

Swanson, L. W. 1949. Topographical manual, part 2, photogrammetry. U.S. Dep. Comm., Spec. Publ. No. 249, 570 p.

Thayer, G. W., W. J. Kenworthy, and M. S. Fonseca. 1984. The ecology of eelgrass meadows of the Atlantic coast: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/02. 147 p.

Thomas, J. P., and R. L. Ferguson. 1990. National Oceanic and Atmospheric Administration's habitat mapping under the Coastal Ocean Program. In federal coastal wetland mapping programs, (S. J. Kiraly, F. A. Cross and J. D. Buffington, eds), p. 27-37. U.S. Fish Wildl. Serv. Biol. Rep. 90 (18).

Thomas, J. P., R. L. Ferguson, J. E. Dobson, and F. A. Cross. 1991. NOAA's CoastWatch: Change Analysis Program. Coastal Wetlands Coastal Zone '91 Conference-, Long Beach, Calif., July 1991, p. 259-267. Thrower, N. J. W., and J. R. Jensen. 1976. The orthophoto and orthophotomap: characteristics, development and application. *Am. Cartographer* 3(1):39-56.

Wang, J., P. M. Treitz, and P. J. Howarth. 1992. Road network detection from SPOT imagery for updating geographical information systems in the rural-urban fringe. *Int. J. Geogr. Inform. Syst.* 6(2):141-157.

Welch, R., M. Remillard, and J. Alberts. 1992. Integration of GPS, remote sensing, and GIS techniques for coastal resource management. *Photogramm. Eng. Remote Sensing* 58:1571-1578.

Westmoreland, S., and D. A. Stow. 1992. Category identification of changed land-use polygons in an integrated image processing/geographic information system. *Photogramm. Eng. Remote Sensing* 58:1593-1599.

Wilén, B. O. 1990. The U.S. Fish and Wildlife Service's National Wetlands Inventory. In federal coastal wetland mapping programs, (S. J. Kiraly, F. A. Cross and J. D. Buffington, eds), p. 9-19. U.S. Fish Wildl. Serv. Biol. Rep. 90 (18).

U. S. Congress. 1989. Coastal waters in jeopardy: reversing the decline and protecting America's coastal resources. Oversight Report of the Committee on Merchant Marine and Fisheries, Serial 100-E, U.S. Govt. Print. Off., Washington, D.C. 47 p.

U. S. Geological Survey. National Mapping Program. 1992. Standards for digital line graphs for land use and land cover, technical instructions. Referral ST0-1- 2.

Zieman, J. C. 1982 The ecology of the seagrasses of south Florida: a community profile. U.S. Fish Wildl. Serv., FWS/OBS-82/25. 185 p.

Zieman, J. C., and R. T. Zieman. 1989. The ecology of the seagrass meadows of the west coast of Florida: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.25). 185 p.

Appendices

Appendix 1.

U.S. Geological Survey Land Use and Land Cover Classification System for Use with Remote Sensor Data

Table A1. summarizes the Level I and Level II elements of the U.S. Geological Survey's Land Use and Land Cover Classification System for use with Remote Sensor Data (Anderson et al. 1976; USGS 1992).

Table A1. U.S. Geological Survey Land Use and Land Cover Classification System for Use with Remote Sensor Data (Anderson et al., 1976; USGS, 1992)¹

- Level
- 1 Urban or Built-Up Land
 - 11 Residential
 - 12 Commercial and Services
 - 13 Industrial
 - 14 Transportation, Communications and Utilities
 - 15 Industrial and Commercial Complexes
 - 16 Mixed Urban or Built-Up
 - 17 Other Urban or Built-up Land
 - 2 Agricultural Land
 - 21 Cropland and Pasture
 - 22 Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural Areas
 - 23 Confined Feeding Operations
 - 24 Other Agricultural Land
 - 3 Rangeland
 - 31 Herbaceous Rangeland
 - 32 Shrub-Brushland Rangeland
 - 33 Mixed Rangeland
 - 4 Forest Land
 - 41 Deciduous Forest Land
 - 42 Evergreen Forest Land
 - 43 Mixed Forest Land
 - 5 Water
 - 51 Streams and Canals
 - 52 Lakes
 - 53 Reservoirs
 - 54 Bays and Estuaries

6 Wetland

61 Forested Wetland

62 Nonforested Wetland

7 Barren Land

71 Dry Salt Flats

72 Beaches

73 Sandy Areas Other than Beaches

74 Bare Exposed Rock

75 Strip Mines, Quarries, and Gravel Pits

76 Transitional Areas

77 Mixed Barren land

8 Tundra

81 Shrub and Brush Tundra

82 Herbaceous Tundra

83 Bare Ground Tundra

84 Wet Tundra

85 Mixed Tundra

9 Perennial Snow or Ice

91 Perennial Snowfields

92 Glaciers

Appendix 2.

U.S. Fish and Wildlife Service Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979)

Table A2. summarizes the classification hierarchy of wetlands and deepwater habitats, showing Systems, Subsystems, and classes of the U.S. Fish and Wildlife Service Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979).

System	Subsystem	Class
Marine	Subtidal	Rock Bottom Unconsolidated Bottom Aquatic Bed Reef
	Intertidal	Aquatic Bed Reef Rocky Shore Unconsolidated Shore

Estuarine	Subtidal	Rock Bottom Unconsolidated Bottom Aquatic Bed Reef
	Intertidal	Aquatic Bed Reef Streambed Rocky Shore Unconsolidated Shore Emergent Wetland Scrub/Shrub Wetland Forested Wetland
Riverine	Tidal	Rock Bottom Unconsolidated Bottom Aquatic Bed Streambed Rocky Shore Unconsolidated Shore Emergent Wetland
	Lower Perennial	Rock Bottom Unconsolidated Bottom Aquatic Bed Rocky Shore Unconsolidated Shore Emergent Wetland
	Upper Perennial	Rock Bottom Unconsolidated Bottom Aquatic Bed Rocky Shore Unconsolidated Shore
Lacustrine	Limnetic	Rock Bottom Unconsolidated Bottom Aquatic Bed
	Littoral	Rock Bottom Unconsolidated Bottom Aquatic Bed Rocky Shore Unconsolidated Shore Emergent Wetland

Palustrine	Rock Bottom Unconsolidated Bottom Aquatic Bed Unconsolidated Shore Moss-Lichen Wetland Emergent Wetland Scrub/Shrub Wetland Forested Wetland
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Appendix 3.

C-CAP Coastal Land Cover Classification System Definitions

The C-CAP Coastal Land Cover Classification System, described in [Chapter 2](#) (Table 1), was developed to meet C-CAP requirements (Klemas et al. 1993). It is intended to be compatible with other classification systems to facilitate the exchange of data among related programs, especially USGS, NWI, and EPA's EMAP. Those classes underlined in Table 1 are of greatest importance to the C-CAP program and most can be detected by satellite sensors such as TM and SPOT.

The system starts with three superclasses: 1.0 Uplands, 2.0 Wetlands, and 3.0 Water and Submerged Land. These superclasses are subdivided into classes and subclasses at the second and third levels, respectively. Most of the classes and subclasses in the C-CAP system are taken from Anderson et al. (1976), Cowardin et al. (1979) and USGS (1992). However, a few definitions have been modified to resolve conflicts between Anderson and Cowardin categories, and some finer categories have been added (e.g., High Intensity Developed Land, Low Intensity Developed Land).

1.0 UPLAND

The superclass 1.0 Upland is divided into seven classes: 1.1 Developed Land, 1.2 Cultivated Land, 1.3 Grassland, 1.4 Woody Land, 1.5 Bare Land, 1.6 Tundra, and 1.7 Snow/Ice.

1.1 DEVELOPED LAND

This class is composed of areas of intensive anthropogenic use. Much of the land is covered by structures and impervious surfaces. Anderson et al. (1976) called these areas "Urban or Built-up Land" although the definition clearly included suburban and rural areas.

"Included in this category are cities; towns; villages; strip developments along highways; transportation, power, and communications facilities; and areas such as those occupied by mills, shopping centers, industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas."

To clarify this apparent contradiction, C-CAP specifies all constructed surfaces regardless of land use.

Developed Lands are divided into two Level II groups: 1.11 - High Intensity, and Low Intensity.

1.11 High Intensity (Solid Cover)

High Intensity, Developed Land includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of different land uses. The High Intensity category contains areas in which a significant land area is covered by concrete and asphalt or other constructed materials. Vegetation, if present, occupies < 20 per cent of the landscape. Examples of such areas include apartment buildings, skyscrapers, shopping centers, factories, industrial complexes, large barns, airport runways, and interstate highways.

1.12 Low Intensity (Mixed Pixels)

Low Intensity, Developed Land includes areas with a mixture of constructed materials (eg. roofing, metal, concrete, asphalt) and vegetation or other cover. Constructed materials account for 50 to 79 per cent of total area. These areas commonly include single-family housing areas, especially in suburban neighborhoods, but may include scattered surfaces associated with all types of land use. As the percentage of constructed material cover decreases, this category grades into Cultivated, Grassland, Woody, and other land cover classes. A large building surrounded by several acres of grass, for example, might appear as one or more pixels of High Intensity Developed Land, one or more pixels of Low Intensity Developed Land and many pixels of Grassland.

1.2 CULTIVATED LAND

Agricultural Land in the Anderson et al. (1976) classification system and was defined as: "... land used primarily for production of food and fiber. On high- altitude imagery, the chief indications of agricultural activity will be distinctive geometric field and road patterns on the landscape and the traces produced by livestock or mechanized equipment."

C-CAP renamed this class "Cultivated Land" to emphasize land cover rather than land use. This category contains areas that have been planted, tilled, or harvested. Pastures and hayfields that are in a state of tilling or planting are also included. Otherwise, pasture or hayfield with well-established grasses are placed in the Grassland category (3.0).

The Cultivated Land class is divided into three subclasses: 1.21 - Orchards/Groves/ Nurseries, 1.22 - Vines/Bushes, and 1.23 - Cropland.

1.21 Orchards/Groves/Nurseries

This category includes woody-stemmed crops that are dominated by single- stemmed, woody vegetation unbranched 0.6 to 0.9 m (2 to 3 feet) above the ground, having a height > 3 m (10 feet). Some examples of the crops included are apple and cherry orchards, and palm date groves. Anderson et al. (1976) states: "Orchards and groves produce the various fruits and nut crops. Tree nurseries that provide seedlings for plantation forestry also are included".

Isolated fruit trees and other orchards substantially smaller than the areal unit of observation are not included.

Pine plantations are not included in this class; they are assigned to the Forest, Evergreen, Woody category (1.412).

1.22 Vines/Bushes

Vine/Bush/Vineyards refers to areas of multiple stemmed, woody-stemmed crops that are shrubs < 3 m (10 feet) in height. Examples of crops included in this category are blueberries and grapes and other vines and bushes producing various fruit or nut crops (Anderson et al., 1976). This group has a different spectral signature than other Cultivated Land groups because of the size and spatial configuration of the vines, shrubs and bushes.

1.23 Cropland

This class of Cultivated Land refers to any crop type that is planted on a regular basis. Crops may be planted annually in the same field year after year or on a rotating schedule. Anderson et al. (1976) states: "The several components of Cropland now used for agricultural statistics include: cropland harvested, including bush fruits; cultivated summer-fallow and idle cropland, land on which crop failure occurs; and cropland in soil-improvement grasses and legumes".

C-CAP has modified this category to emphasize the instantaneous state of the land at the time of observation. Hence, for example, Cultivated Land in a five-year rotation scheme will be categorized as Cropland for the four years the land is tilled and Grassland for the one year the land is fallow and covered by grasses. A fallow period of several years may result in a transition from Cropland to Grassland to Scrub/Shrub and back to Cropland.

Nurseries and horticultural areas (which include floriculture, seed, and sod areas) used perennially for those purposes are included in this category if woody-stemmed plants are not grown. Greenhouses normally fall in the Developed category.

1.3 GRASSLAND

The Grassland category includes lands covered by natural and managed herbaceous cover. Grassland historically has been defined as land where the potential natural vegetation is predominantly grasses, grass-like plants, and forbs, and where natural herbivory was an important influence in its pre civilization state. Anderson et al. (1976) state:

"Some grasslands have been or may be seeded to introduce or domesticate plant species. The Grassland (Herbaceous) category contains both managed and unmanaged or natural herbaceous cover. The Grassland (Herbaceous) category can be found in every state in the United States along with Canada and Mexico."

The C-CAP category includes lands with herbaceous cover at the time of observation regardless of origin or potential. Pastures, hayfields, and natural rangelands are included. Also included are lawns and other managed grassy areas such as parks, cemeteries, golf courses, road rights-of-way, and other herbaceous-covered, landscaped areas.

The Grassland class is divided into two subclasses: 1.31 - Unmanaged and 1.32 - Managed.

1.31 Unmanaged

The Unmanaged, Herbaceous, Grasslands category refers to herbaceous cover allowed to grow naturally and not fertilized, cut, or tilled and planted regularly. This category includes, but is not limited to, the Anderson et al. (1976) "Herbaceous Rangeland" category:

"the tall grass (or true prairie), short grass, bunch grass or palouse grass, and desert grass regions...Bunch

grass and desert grass are found in many locations, representing transitional situations to desert shrub. Typical occurrences of grasslands include such species as the various bluestems (*Andropogon*), grama grasses (*Bouteloua*), wheat-grasses (*Agropyron*), needle-grasses (*Stipa*), and fescues (*Festuca*). This category also includes the palmetto prairie areas of south-central Florida, which consist mainly of dense stands of medium length and tall grasses such as wiregrass (*Aristida stricta*) and saw palmettos (*Serenoa ripens*), interspersed occasional palms (*Sabal palmetto*), and shrubs."

Unmanaged grasslands occur throughout the United States, often as a transitional phase in the regrowth of abandoned Cropland, clearcut Woody Land, or land impacted by natural disturbance.

1.32 Managed Grassland

These grasslands are maintained by human activity and include lawns, golf courses, pastures, hayfields, and other areas of grassland in which seeding, fertilization, or irrigation enhance biomass productivity. This category may contain vegetation that grows as fallow if vigorous growth persists due to the residual effects of management practices in the non-fallow state.

1.4 WOODY LAND

The Woody Land class includes any species with an aerial stem that persists for more than one season. The Woody class is divided into three subclasses: 1.41 - Deciduous, 1.42 - Evergreen, and 1.43 - Mixed.

1.4 Deciduous

The Deciduous Woody subclass includes all forest and shrub areas having a predominance of trees and shrubs that lose their leaves or needles at the end of the frost-free season or at the beginning of a dry season. This category contains greater than two-thirds deciduous trees and shrubs. The Deciduous Woody category can be divided into two groups: 1.411 - Forest and 1.412 - Scrub/Shrub.

1.411 Forest

Deciduous Forest includes areas dominated by single stemmed, woody vegetation unbranched 2-3' above the ground having a height > 6 m (20 feet). Forest Deciduous Woody areas have a tree-crown areal density (crown closure percentage) of > 10 percent, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime. In most parts of the United States, these would be the hardwoods such as oak (*Quercus*), maple (*Acer*), or hickory (*Carya*) and the "soft" hardwoods, such as aspen (*Populus tremuloides*). Tropical hardwoods are included in the Evergreen Forest (Land) category (4.21). Deciduous forest types characteristic of Wetland, such as tupelo (*Nyssa*) or cottonwoods (*Populus deltoides*), are not included in this category.

1.412 Scrub/Shrub

Deciduous Scrub/Shrub includes all areas having a predominance of shrub that lose their leaves or needles at the end of the frost-free season or at the beginning of the dry season (Anderson et al. 1976). This category contains vegetation that is < 6 meters (20 feet) in height. The species include true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions. True shrubs are those woody stemmed species that exhibit several erect, spreading or prostrate stems and a general bushy appearance. Shrub Lands may represent a successional stage leading to forests or they may be relatively stable communities. Forest regrowth composed of young trees < 6 m tall is also included in

this category.

1.42 EVERGREEN

The Evergreen Woody subclass contains forests and shrubs that do not lose their leaves or needles at the end of a frost-free season or at the beginning of a dry season. The Evergreen Woody category is subdivided into two additional categories: 1.421 - Forest, and 1.422 - Scrub/Shrub.

1.421 Forest

Evergreen Forest includes areas in which > 67 per cent of the trees remain green throughout the year. Both coniferous and broad-leaved evergreens are included in this category. Coniferous evergreens predominate, except in tropical regions where broad-leaved evergreens are indigenous. Coniferous evergreens, often called softwoods, include such eastern species as the longleaf pine (*Pinus palustris*), slash pine (*Pinus ellioti*), shortleaf pine (*Pinus echinata*), loblolly pine (*Pinus taeda*), and other southern yellow pines; various spruces (*Picea*) and balsam fir (*Abies balsamea*); white pine (*Pinus strobus*), red pine (*Pinus resinosa*), and jack pine (*Pinus banksiana*); and hemlock (*Tsuga canadensis*); and such western species as Douglas-fir (*Pseudotsuga menziesii*), redwood (*Sequoia sempervirens*), ponderosa pine (*Pinus monticola*), Sitka spruce (*Picea sitchensis*), Engelmann spruce (*Picea engelmanni*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*). Evergreen species commonly associated with Wetland, such as tamarack (*Larix laricina*) or black spruce (*Picea mariana*), are not included in this category.

1.422 Scrub/Shrub

Evergreen Scrub/Shrub includes areas in which > 67 per cent of the shrubs remain green throughout the year. Anderson et al. (1976) states:

"Both coniferous and broad-leaved evergreens are included in this category. The typical Shrub Lands are found in those arid and semiarid regions characterized by such xerophytic vegetative types with woody stems as big sagebrush (*Artemisia tridentata*), shadscale (*Atriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*), and creosotebush (*Larrea divaricata*). When bottom lands and moist flats are characterized by dense stands of typical wetland species...they are considered Wetland. Where highly alkaline soils are present, halophytes such as desert saltbush (*Atriplex*) may occur. The type, density, and association of these various species are useful as indicators of the local hydrologic and pedologic environments. Also included in this category is chaparral, a dense mixture of broadleaf evergreen sclerophyll shrubs, and the occurrences of mountain mahogany (*Cercocarpus ledifolius*) and scrub oaks (*Quercus*)."

1.43 MIXED

The Mixed Woody class includes all forest and shrub areas where both evergreen and deciduous trees and shrubs grow and neither predominates. When evergreen and deciduous species each respectively occupy > 33 percent of an area, the land it is classified as Mixed Woody. The Mixed Woody category is subdivided into two additional categories: 1.431 - Forest, and 1.432 - Scrub/Shrub.

1.431 Forest

This class includes all forested areas where both evergreen and deciduous trees are growing and neither predominate.

1.432 Scrub/Shrub

This class includes all shrub areas where both evergreen and deciduous shrubs are growing and neither predominate.

1.5 BARE LAND

Bare Land, modified from "Barren Land" in Anderson et al., 1976, is composed of bare rock, sand, silt, gravel, or other earthen material with little or no vegetation regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the vegetated categories. Unusual conditions, such as a heavy rainfall, occasionally may result in a short-lived, luxuriant plant cover. Wet, nonvegetated exposed lands are included in the wetland categories.

Categories of Bare Land include dry salt flats, beaches, sandy areas other than beaches, bare exposed rock, strip mines, quarries, gravel pits, transitional areas, and mixed barren land:

Dry Salt Flats are level bottoms of interior desert basins which capture infrequent rainfall and do not qualify as Wetland. Salt concentrations result in highly reflective surfaces.

Sandy Areas other than Beaches are composed primarily of dunes - accumulations of sand transported by the wind. Sand accumulations most commonly are found in deserts although they also occur on coastal plains, river flood plains, and deltas and in periglacial environments. When such sand accumulations are encountered in tundra areas, they are not included here but are placed in the Bare Ground Tundra category.

Bare Exposed Rock includes areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, and other accumulations of rock without vegetative cover, with the exception of such rock exposures occurring in tundra regions.

Strip Mines, Quarries, and Gravel Pits are extractive mining activities with significant surface expression. Vegetative cover and overburden are removed to expose such deposits as coal, iron ore, limestone, and copper. Quarrying of building and decorative stone and recovery of sand and gravel deposits also result in large open surface pits. Active, inactive, and unreclaimed strip mines, quarries, borrow pits, and gravel pits are included in this category until other cover has been established, after which the land is classified in accordance with the resulting cover. Unused pits or quarries that have been flooded, however, are placed in the appropriate Water category.

Transitional Areas are dynamically changing from one land cover to another, often due to land use activities. This transitional phase occurs when, for example, forest lands are cleared for agriculture and wetlands are drained for development. Often land becomes temporarily bare as construction initiates the transition from Woody Land or Grassland to a future cover associated with residential, commercial, or other intensive land use. Lands, such as spoil banks and sanitary landfills, temporarily altered by grading and filling are considered transitional.

1.6 TUNDRA

Tundra is the term applied to the treeless cover beyond the latitudinal limit of the boreal forest in poleward regions and above the elevation range of the boreal forest in high mountains. In the United States, tundra occurs primarily in Alaska, several areas of the western high mountain ranges, and isolated enclaves in the high mountains of New England and northern New York.

The vegetative cover of the tundra is low and dwarfed and often forms a continuous mat. Plant characteristics are an adaptation to an extreme physical environment in which temperatures may average above freezing only 1 or 2 months out of each year, strong desiccating winds may occur, great variation exists in solar energy, and permafrost is ubiquitous beneath the surface.

The number of species in the flora is relatively small compared with typical middle- and low-latitude flora, and the number decreases as the environment becomes more severe with increasing latitude and elevation. The tundra vegetation is most luxuriant near the boreal forest. Conversely, plant density and species diversity are lowest near the boundaries of permanent ice and snow areas, where only isolated patches of vegetation occur on generally bare surfaces.

Tundra may be further subdivided into: Shrub and Brush Tundra, Herbaceous Tundra, Bare Ground Tundra, Wet Tundra, and Mixed Tundra (Anderson et al. 1976).

1.7 SNOW/ICE

The temporal dimension is crucial in determining snow and ice cover. Any snowfall, for example, deep enough to conceal another land cover, no matter how briefly, comprises the visible surface at that time and technically constitutes the land cover for the period of its duration. As a practical matter, of course, analysts usually need to characterize the land cover persisting for a greater portion of the year. At higher latitudes and elevations, snow and ice persist for greater portions of the year, and seasonal coverage becomes a more important concern. At extreme latitudes and elevations, perennial Snow/Ice cover is of paramount interest. A combination of environmental factors may cause snow and ice to survive the summer melting season. Areas of perennial Snow/Ice cover are defined as those where snow, firn (coarse, compacted granular snow), or ice accumulation exceeds ablation. Ablation is the combined loss of snow or ice mass by evaporation and melt-water run-off (Anderson et al. 1976).

The class Snow/Ice contains two subclasses: 1.71 - Perennial Snow/Ice, and 1.72 - Glacier.

1.71 Perennial Snow/Ice

This class contains areas covered year-round with snow and ice but which have not accumulated sufficient ice to be considered Glaciers. Snowfields can be extensive and thus representative of a regional climate, or can be isolated and localized, where they are known by various terms, such as snowbanks. The regional snowline is controlled by general climatic conditions and closely parallels the regional 32 degrees F. (0 degrees C.) isotherm for the average temperature of the warmest summer month. The use of the term "line" is somewhat misleading, because the "snowline" represents an irregular transitional boundary, which is determined at any single location by the combination of snow accumulation, snow melt, and ablation, variables that can change rapidly within short distances because of changes in local topography and slope orientation. Snowfields normally can be distinguished from the following Glacier category by their relative lack of flow features (Anderson et al. 1976).

1.72 Glaciers

Glacial ice originates from the compaction of snow into firn and finally to ice under the weight of several successive annual accumulations. Refrozen melt water usually contributes to the increasing density of the glacial ice mass. With sufficient thickness, weight, and bulk, flow begins, and all glaciers exhibit evidence of present or past motion in the form of moraines, crevasses, and other glacial geomorphic features.

Where the snowline of adjacent ice-free areas extends across the glacier, it is known as the firm limit, which represents the dividing line between the glacier's two major zones, the zone of accumulation and the zone of ablation. While glaciers normally are recognized easily, certain glacial boundaries may be subject to misinterpretation, even by the experienced interpreter. Flow features up-glacier from the firm limit typically are obscured by fresh snow, forcing the image interpreter to depend on secondary information such as valley shapes or seek a more discriminating sensor. Similarly, glacial drift materials (rock and soil) may stripe the surface of a glacier, and moraine material may cover the terminus (or snout) because of ablation, making boundary determination in that vicinity difficult. This latter problem occasionally is compounded by the presence of considerable vegetation rooted in the insulating blanket of ablation moraine (Anderson et al. 1976).

2.0 Wetland

Cowardin et al. (1979) define wetlands as lands where saturation with water is the dominant factor determining soil development and the types of plant and animal communities living in the soil and on its surface. The single feature that all wetlands share is soil or substrate that is at least periodically saturated with or covered by water. The upland limit for vegetated wetlands with soil is 1) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover; 2) for non-vegetated wetlands with soil the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric; or 3) in the case of wetlands without vegetation or soil, the boundary between land that is flooded or saturated at some time during the growing season each year and land that is not. The majority of all wetlands are vegetated and are found on soil.

In the C-CAP Coastal Land Cover Classification System (Table 1), "Wetland" includes all areas considered wetland by Cowardin et al. (1979) except for Wetland Bottoms, Aquatic Beds, and Nonpersistent Emergent Wetlands. Subdivision of the Wetlands class closely resembles the Cowardin system (Appendix 2). At Level II C-CAP used certain Cowardin classes (e.g., Rocky Shore, Unconsolidated Shore, Emergent Wetland) or grouped Cowardin classes (e.g., Woody Wetland = Scrub-Shrub + Forested Wetland), in combination with Cowardin et al. systems (i.e., Marine, Estuarine, Riverine, Lacustrine, Palustrine). Thus, C-CAP Level II wetland classes became 2.1 Marine/Estuarine Rocky Shore, 2.2 Marine/Estuarine Unconsolidated Shore, 2.3 Marine/Estuarine Emergent Wetland, 2.4 Estuarine Woody Wetland, 2.5 Riverine Unconsolidated Shore, 2.6 Lacustrine Unconsolidated Shore, 2.7 Palustrine Unconsolidated Shore, 2.8 Palustrine Emergent Wetland (persistent), and 2.9 Palustrine Woody Wetland.

Salinity displays a horizontal gradient in marshes typical of coastal plain estuaries. This is evident not only through the direct measurement of salinity but in the horizontal distribution of marsh plants, in marshes with positive correlations between vertical rise and landward location (Daiber 1986). Therefore Estuarine Emergent Wetlands were partitioned into Haline (Salt) and Mixohaline (Brackish) Marshes. For both subclasses, the definitions used in Cowardin et al. (1979) were used; i.e. the salinity for the Mixohaline range from 0.5 ppt to 30 ppt and for Haline includes salinities > 30 ppt. Within a marsh, plant zonation is usually quite evident. Along the Atlantic coast of North America the pioneer plant is Saltmarsh cordgrass, *Spartina alterniflora*, which often appears in pure stands. Higher up the slope Saltmeadow hay, *Spartina patens* becomes dominant, while the upland edges are bordered by Marsh elder, *Iva frutescens* and Groundsell tree, *Baccharis halimifolia*. Thus, salt marshes could be subdivided further into High Marsh and Low Marsh.

C-CAP does not attempt to identify Nonpersistent Emergent Wetlands because they are seasonal. These

wetlands are classified as "Riverine Water" and "Lacustrine Water," respectively. Marine and Estuarine Rocky Shores were combined into a single class, Marine/Estuarine Rocky Shore. The same logic was applied to create Marine and Estuarine Unconsolidated Shores, Aquatic Beds, and Water.

3.0 Water and Submerged Land

All areas of open water with < 30% cover of trees, shrubs, persistent emergent plants, emergent mosses, lichens, or other land cover are grouped under the heading, Water and Submerged Land, regardless of whether the area is considered wetland or deepwater habitat under the Cowardin et al. (1979) classification system. The Level II C-CAP Water and Submerged Land classes are modified from Cowardin et al. (1979) (Appendix 2), and include "Water," "Reef," and "Aquatic Beds". Marine and Estuarine Reefs and Marine and Estuarine Aquatic Beds are combined into two classes, 3.2 Marine/Estuarine Reefs and 3.3 Marine/Estuarine Aquatic Beds. Aquatic beds in rivers, lakes and streams are assigned to 3.4 Riverine Aquatic Bed, 3.5 Lacustrine Aquatic Bed, and 3.6 Palustrine Aquatic Bed classes. This class also includes Cowardin et al.'s (1979) Rock Bottom and Unconsolidated Bottoms.

Most C-CAP products will designate water as a single class (3.1) regardless of system type. It is recognized, however, that the major systems (Marine/Estuarine, Riverine, Lacustrine, Palustrine) are ecologically quite different from one another. Hence, the four systems at Level III are shown as subclasses, i.e., 3.11 Marine/Estuarine Water, 3.12 Riverine Water, 3.13 Lacustrine Water, and 3.14 Palustrine Water. Even though C-CAP does not commit itself to provide the subclass data, this option is encouraged for regional participants. Incorporating water system information makes the C-CAP scheme more compatible with the Cowardin System. The subclass 3.11 Marine/Estuarine Water includes bottoms and undetected reefs and aquatic beds. The subclasses 3.12 Riverine Water, 3.13 Lacustrine Water, and 3.14 Palustrine Water include bottoms and undetected aquatic beds or non-persistent emergent wetlands.

3.3 Marine/Estuarine Aquatic Beds include the subclass Rooted Vascular which is broken into High Salinity (> 5 ppt) and Low Salinity (< 5 ppt). The break was made at 5 ppt salinity because it separates true seagrasses which require high salinity from low salinity and fresh water tolerant or requiring species. Both low and high salinity types of SRV are important to the C-CAP project. High Salinity includes Cowardin's mesohaline, polyhaline, euhaline, and hyperhaline salinity categories. Low Salinity includes Cowardin's oligohaline and fresh categories.

Appendix 4.

Description of the Cowardin et al. Systems and Classes

Most of the C-CAP wetland and water definitions are taken directly from Cowardin et al. (1979). This classification is hierarchical, progressing from Systems and Subsystems, at the most general level, to classes, subclasses, and dominance types. Appendix 2 (Table A2) illustrates the hierarchical structure to the class level. Modifiers for water regime, water chemistry, and soils are applied to classes, subclasses, and dominance types. Special modifiers describe wetlands and deepwater habitats that have been either created or highly modified by human activity or beaver activity.

A. Systems

The term system refers to a complex of wetlands and deepwater habitats that share the influence of similar hydrologic, geomorphologic, chemical, or biological factors. Systems are subdivided into subsystems.

The characteristics of the five major Systems--Marine, Estuarine, Riverine, Lacustrine, and Palustrine--have been discussed at length in the scientific literature and the concepts are well recognized. However, there is disagreement as to which attributes should be used to bound the Systems in space. For example, both the limit of tidal influence and the limit of ocean-derived salinity have been proposed as definitions of the upstream limit of Estuarine Systems (Caspers 1967). As Bormann and Likens (1969) affirm, boundaries of ecosystems are defined to meet practical needs.

Marine System

Definition. The Marine System consists of the open ocean overlying the continental shelf and its associated high-energy coastline. Marine habitats are exposed to the waves and currents of the open ocean and the water regimes are determined primarily by the ebb and flow of ocean tides. Salinities exceed 3.0 ppt., with little or no dilution except near the mouths of estuaries. Shallow coastal indentations or bays without appreciable freshwater inflow, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind and waves, are also considered part of the Marine System because they generally support typical marine biota.

Limits. The Marine System extends from the outer edge of the continental shelf shoreward to one of three lines: (1) the landward limit of tidal inundation (extreme high water of spring tides), including the splash zone from breaking waves; (2) the seaward limit of wetland emergents, trees, or shrubs; or (3) the seaward limit of the Estuarine System, where this limit is determined by factors other than vegetation. Deepwater habitats lying beyond the seaward limit of the Marine System are outside the scope of this classification system.

Estuarine System

Definition. The Estuarine System consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semi enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land. The salinity may be periodically increased above that of the open ocean by evaporation. Along some low-energy coastlines there is appreciable dilution of sea water. Offshore areas with typical estuarine plants and animals, such as red mangroves (*Rhizophora mangle*) and eastern oysters (*Crassostrea virginica*), are also included in the Estuarine System.

Limits. The Estuarine System extends (1) upstream and landward to where ocean-derived salts measure < 0.5 ppt. during the period of average annual low flow; (2) to an imaginary line closing the mouth of a river, bay, or sound; and (3) to the seaward limit of wetland emergents, shrubs, or trees where they extend beyond the river mouth defined by (2). The Estuarine System also includes offshore areas of continuously diluted sea water.

Riverine System

Definition. The Riverine System includes all wetlands and deepwater habitats contained within a channel, except: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts > 0.5 ppt. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water".

Limits. The Riverine System is bounded on the landward side by upland, by the channel bank (including natural and man-made levees), or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. In braided streams, the system is bounded by the banks forming the outer limits of the depression within which the braiding occurs.

The Riverine System terminates downstream where the concentration of ocean-derived salts in the water exceeds 0.5 ppt. during the period of annual average low flow, or where the channel enters a lake. It terminates upstream where tributary streams originate or where the channel originates from a lake. Springs discharging into a channel are considered part of the Riverine System.

Lacustrine System

Definition. The Lacustrine System includes wetlands and deepwater habitats with all of the following characteristics: (1) situated in a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with $> 30\%$ areal coverage; and (3) total area > 8 ha (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary, or if the water depth in the deepest part of the basin is > 2 m (6.6 feet) at low water. Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always < 0.5 ppt.

Limits. The Lacustrine System is bounded by upland or by wetland dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens. Lacustrine Systems formed by damming a river channel are bounded by a contour approximating the normal spillway elevation or normal pool elevation, except where Palustrine wetlands extend lakeward of that boundary. Where a river enters a lake, the extension of the Lacustrine shoreline forms the Riverine-Lacustrine boundary.

Palustrine System

Definition. The Palustrine System includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5%. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) the area is < 8 ha (20 acres); (2) active wave- formed or bedrock shoreline features are lacking; (3) water depth in the deepest part of basin is < 2 m at low water; and (4) salinity due to ocean-derived salts is < 0.5 ppt.

Limits. The Palustrine System is bounded by upland or by any of the other four Systems.

Description. The Palustrine System was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie pothole, which are found throughout the United States. It also includes small, shallow, permanent or intermittent water bodies often called ponds (except in New England and New York where the term pond often refers to substantial lakes). Palustrine wetlands may be situated shoreward of lakes, river channels, or estuaries; on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. The erosive forces of wind

and water are of minor importance except during severe floods.

B. Classes and Subclasses

The class is the highest taxonomic unit below the Subsystem level. It describes the general appearance of the habitat in terms of either the dominant life form of the vegetation or the physiography and composition of the substrate--features that can be recognized without the aid of detailed environmental measurements. Vegetation is used at two different levels in the classification. The life forms--trees, shrubs, emergents, emergent mosses, and lichens--are used to define classes because they are relatively easy to distinguish, do not change distribution rapidly, and have traditionally been used as criteria for classification of wetlands. Other forms of vegetation, such as submersed or floating-leaved rooted vascular plants, free-floating vascular plants, submergent mosses, and algae, though frequently more difficult to detect, are used to define the class Aquatic Bed. Pioneer species that briefly invade wetlands when conditions are favorable are treated at the subclass level because they are transient and often are not true wetland species (Cowardin et al. 1979).

Use of life forms at the class level has two major advantages: (1) extensive biological knowledge is not required to distinguish between various life forms, and (2) it has been established that various life forms are easily recognizable on a great variety of remote sensing products (Anderson et al. 1976) If vegetation (except pioneer species) covers > 30% of the substrate, classes are distinguished on the basis of the life form of the plants that constitute the uppermost layer of vegetation and that occupy an areal coverage > 50% of vegetative cover. Finer differences in life forms are recognized at the subclass level. For example, in the C-CAP system Woody Wetland is divided into the subclasses Forested Wetland and Scrub/Shrub Wetland categories, each of which may be further characterized as Deciduous, Evergreen, and Mixed on the basis of predominant life form. This differs somewhat from the Cowardin system which distinguishes trees from shrubs at the class level.

If vegetation covers < 30% of the substrate, the physiography and composition of the substrate are the principal characteristics used to distinguish classes. The nature of the substrate reflects regional and local variations in geology and the influence of wind, waves, and currents on erosion and deposition of substrate materials. Bottoms, Shores, and Streambeds are separated on the basis of duration of inundation. In the Riverine, Lacustrine, and Palustrine Systems, Bottoms are submerged all or most of the time, whereas Streambeds and Shores are exposed all or most of the time. In the Marine and Estuarine Systems, Bottoms are Subtidal, whereas Streambeds and Shores are Intertidal. Bottoms, Shores, and Streambeds are further divided at the class level on the basis of the important characteristic of rock versus unconsolidated substrate. Subclasses are based on finer distinctions in substrate material unless, as with Streambeds and Shores, the substrate is covered by, or shaded by, an areal coverage of pioneering vascular plants (often nonhydrophytes) > 30%. The subclass is then simply "vegetated." Further detail as to the type of vegetation must be obtained at the level of dominance type. Reefs are a unique class in which the substrate itself is composed primarily of living and dead animals. Subclasses of Reefs are designated on the basis of the type of organism that formed the reef.

As shown in Table A2 of Appendix 2, the classes defined in Cowardin et al. (1979) include:

- Rock Bottom (not used in the C-CAP system)
- Unconsolidated Bottom (not used in C-CAP system)
- Aquatic Bed
- Reef

- Streambed (not used in the C-CAP system)
- Rocky Shore
- Unconsolidated Shore
- Emergent Wetland
- Scrub-Shrub Wetland
- Forested Wetland

Aquatic Bed

Definition. The Aquatic Bed class includes wetlands and deepwater habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years. Water regimes include subtidal, irregularly exposed, regularly flooded, permanently flooded, intermittently exposed, semi permanently flooded, and seasonally flooded.

Description. Aquatic Beds represent a diverse group of plant communities that require surface water for optimum growth and reproduction. They are best developed in relatively permanent water or under conditions of repeated flooding. The plants are either attached to the substrate or float freely in the water above the bottom or on the surface. The subclasses are Algal, Aquatic Moss (not used by C-CAP and not defined here), and Rooted Vascular.

Algal.--Algal Beds are widespread and diverse in the Marine and Estuarine Systems, where they occupy substrates characterized by a wide range of sediment depths and textures. They occur in both the Subtidal and Intertidal Subsystems and may grow to depths of 30 m (98 feet). Coastal Algal Beds are most luxuriant along the rocky shores of the Northeast and West. Kelp (*Macrocystis*) beds are especially well developed on the rocky substrates of the Pacific Coast. Dominance types such as the rockweeds *Fucus* and *Ascophyllum* and the kelp *Laminaria* are common along both coasts. In tropical regions, green algae, including forms containing calcareous particles, are more characteristic; *Halimeda* and *Penicillus* are common examples. The red alga *Laurencia*, and the green algae *Caulerpa*, *Enteromorpha*, and *Ulva* are also common Estuarine and Marine dominance types; *Enteromorpha* and *Ulva* are tolerant of fresh water and flourish near the upper end of some estuaries. The stonewort *Chara* is also found in estuaries.

Inland, the stoneworts *Chara*, *Nitella*, and *Tolypella* are examples of algae that look much like vascular plants and may grow in similar situations. However, meadows of *Chara* may be found in Lacustrine water as deep as 40 m (131 feet) where hydrostatic pressure limits the survival of vascular submergents (phanaerogams). Other algae bearing less resemblance to vascular plants are also common. Mats of filamentous algae may cover the bottom in dense blankets, may rise to the surface under certain conditions, or may become stranded on Unconsolidated or Rocky Shores.

Rooted Vascular.--Rooted Vascular Beds include a large array of vascular species in the Marine and Estuarine Systems. They have been referred to as temperate grass flats (Phillips 1974), tropical marine meadows, and eelgrass beds, turtlegrass beds, and seagrass beds. The greatest number of species occur in shallow, clear tropical, or subtropical waters of moderate current strength in the Caribbean and along the Florida and Gulf Coasts. Principal dominance types in these areas include turtle grass (*Thalassia testudinum*), shoalgrass (*Halodule wrightii*), manatee grass (*Cymodocea filiformis*), widgeon grass (*Ruppia maritima*), sea grasses (*Halophila* spp.), and wild celery (*Vallisneria americana*).

Reef

Definition. The Reef class includes ridge-like or mound-like structures formed by the colonization and growth of sedentary invertebrates. Water regimes are restricted to subtidal, irregularly exposed, regularly flooded, and irregularly flooded.

Description. Reefs are characterized by their elevation above the surrounding substrate and their interference with normal wave flow; they are primarily subtidal, but parts of some reefs may be intertidal as well. Although corals, oysters, and tube worms are the most visible organisms and are mainly responsible for reef formation, other mollusks, foraminifera, coralline algae, and other forms of life also contribute substantially to reef growth. Frequently, reefs contain far more dead skeletal material and shell fragments than living matter. The subclasses are Coral; Mollusk; and Worm. Only the first subclass is emphasized by C-CAP; the other two definitions are omitted.

Coral.--Coral Reefs are widely distributed in shallow waters of warm seas, in Hawaii, Puerto Rico, the Virgin Islands, and southern Florida. Odum (1971) characterized them as stable, well-adapted, highly diverse, and highly productive ecosystems with a great degree of internal symbiosis. Coral Reefs lie almost entirely within the Subtidal Subsystem of the Marine System, although the upper part of certain Reefs may be exposed. Examples of dominance types are the corals *Porites*, *Acropora*, and *Montipora*. The distribution of these types reflects primarily elevation, wave exposure, and age of reefs.

Rocky Shore

Definition. The Rocky Shore class includes wetland environments characterized by bedrock, stones, or boulders which singly or in combination have an areal cover > 75% and an areal coverage by vegetation of < 30%. Water regimes are restricted to irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, and intermittently flooded.

Description. In Marine and Estuarine Systems, Rocky Shores are generally high-energy habitats which lie exposed as a result of continuous erosion by wind-driven waves or strong currents. The substrate is stable enough to permit the attachment and growth of sessile or sedentary invertebrates and attached algae or lichens. Rocky Shores usually display a vertical zonation that is a function of tidal range, wave action, and degree of exposure to the sun. In the Lacustrine and Riverine Systems, Rocky Shores support sparse plant and animal communities. The subclasses are Bedrock and Rubble. More detailed definitions are provided in Cowardin et al. (1979).

Unconsolidated Shore (Tidal Flats)

Definition. The Unconsolidated Shore class includes all wetland habitats having three characteristics: (1) unconsolidated substrates with < 75% areal cover of stones, boulders, or bedrock; (2) < 30% areal cover of vegetation other than pioneering plants; and (3) any of the following water regimes: irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, or artificially flooded. Intermittent or intertidal channels of the Riverine System and intertidal channels of the Estuarine System are classified as Streambed.

Description. Unconsolidated Shores are characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of landforms such as beaches, bars, and flats, all of which are included in this class. Unconsolidated Shores may be found adjacent to Unconsolidated Bottoms in all Systems. As in Unconsolidated Bottoms, the particle size of the substrate and the water regime are the important factors determining the types of plant and animal communities

present. Different substrates usually support characteristic invertebrate fauna. The subclasses are Cobble-gravel; Sand; and Mud. More detailed definitions are provided in Cowardin et al. (1979).

Emergent Wetland

Definition. The emergent Wetland class is characterized by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens) which are present for most of the growing season in most years. These wetlands are usually dominated by perennial plants. All water regimes are included except subtidal and irregularly exposed.

Description. In areas with relatively stable climatic conditions, Emergent Wetlands maintain the same appearance year after year. In other areas, such as the prairies of the central United States, violent climatic fluctuations cause them to revert to open water in some years. Emergent Wetlands are found throughout the United States and occur in all Systems except the Marine. Emergent Wetlands are known by many names, including marsh, meadow, fen, prairie pothole, and slough. Areas dominated by pioneer plants which become established during periods of low water are not Emergent Wetlands and should be classified as Vegetated Unconsolidated Shores or Vegetated Streambeds. The subclasses in the Cowardin system are Persistent and Nonpersistent.

Woody Wetland

The Woody Wetland class includes any species with an aerial stem that persists for more than one season. The Woody Wetland class is divided into three subclasses: Deciduous, Evergreen, and Mixed.

Deciduous

The Deciduous Woody Wetland subclass includes all wetland forest and shrub areas having a predominance of trees and shrubs that lose their leaves or needles at the end of the frost-free season or at the beginning of a dry season. This category contains greater than two-thirds deciduous trees and shrubs. The Deciduous Woody Wetland category can be divided into three categories: Forest, Scrub/Shrub and Dead.

Forest

Definition. Forested Wetland is characterized by woody vegetation > 6 m in height. All water regimes are included except subtidal. **Description.** Forested Wetlands are most common in the eastern United States and in those sections of the West where moisture is relatively abundant, particularly along rivers and in mountains. They occur only in the Palustrine and Estuarine systems and normally contain an overstory of trees, an understory of young trees or shrubs, and a herbaceous layer. Forested Wetlands in the Estuarine System, including the mangrove forests of Florida, Puerto Rico, and the Virgin Islands, are known by such names as swamps, hammocks, heads, and bottoms. These names often occur in combination with species names or plant associations such as cedar swamp or bottom land hardwoods.

Broad-leaved Deciduous.--Dominant trees typical of Broad-leaved Deciduous Wetlands, which are represented throughout the United States, are most common in the South and East. Common dominants are species such as red maple, American elm (*Ulmus americana*), ashes (*Fraxinus pennsylvanica* and *F. nigra*), black gum (*Nyssa sylvatica*), tupelo gum (*N. aquatica*), swamp white oak (*Quercus bicolor*), overcup oak (*Q. lyrata*), and basket oak (*Q. michauxii*). These wetlands generally occur on mineral soils or highly decomposed organic soils.

Needle-leaved Deciduous.--The southern representative of the Needle-leaved Deciduous is bald cypress (*Taxodium distichum*), which is noted for its ability to tolerate long periods of surface inundation. Tamarack is characteristic of the Boreal Forest Region, where it occurs as a dominant on organic soils. Relatively few other species are included in this subclass.

Scrub/Shrub

Definition. Scrub-Shrub Wetland includes areas dominated by woody vegetation < 6 m (20 feet) tall. The species include true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions. All water regimes except subtidal are included. **Description.** Scrub-Shrub Wetlands may represent a successional stage leading to Forested Wetland, or they may be relatively stable communities. They occur only in the Estuarine and Palustrine Systems, but are one of the most widespread classes in the United States. Scrub-Shrub Wetlands are known by many names, such as shrub swamp, shrub, bog, and pocosin. C-CAP includes forests composed of young trees < 6 m tall regardless of potential height at maturity.

Broad-leaved Deciduous.--In Estuarine System Wetlands the predominant deciduous and broad-leaved trees or shrubs are plants such as sea-myrtle (*Baccharis halimifolia*) and marsh elder (*Iva frutescens*). In the Palustrine System typical dominance types are alders (*Alnus* spp.), willows (*Salix* spp.), buttonbush (*Cephalanthus occidentalis*), red osier dogwood (*Cornus stolonifera*), honeycup (*Zenobia pulverulenta*), spirea (*Spiraea douglasii*), bog birch (*Betula pumila*), and young trees of species such as red maple (*Acer rubrum*) or black spruce (*Picea mariana*).

Needle-leaved Deciduous.--This group, consisting of wetlands where trees or shrubs are predominantly deciduous and needle-leaved, is represented by young or stunted trees such as tamarack or bald cypress (*Taxodium distichum*).

Dead

Definition. Wetland areas dominated by dead deciduous woody vegetation. These wetlands are usually produced by a prolonged rise in the water table resulting from impoundment of water by landslides, human activity, or beaver activity. Such wetlands may also result from various other factors such as fire, salt spray, insect infestation, air pollution, and herbicides.

EVERGREEN

The Evergreen Woody Wetland subclass contains wetland forests and shrubs that do not lose their leaves or needles at the end of a frost-free season or at the beginning of a dry season. The Evergreen Woody Wetland category is subdivided into two additional categories: Forest, and Scrub/Shrub.

Forest

Definition. Forested Wetland is characterized by woody vegetation > 6 m in height. All water regimes are included except subtidal.

Broad-leaved Evergreen.--In the Southeast, Broad-leaved Evergreen Wetlands reach their greatest development. Red bay (*Persea borbonia*), loblolly bay (*Gordonia lasianthus*), and sweet bay (*Magnolia virginiana*) are prevalent, especially on organic soils. This group also includes red mangrove, black

mangrove (*Avicennia germinans*), and white mangrove (*Languncularia racemosa*), which are adapted to varying levels of salinity.

Needle-leaved Evergreen.--Black spruce, growing on organic soils, represents a major dominant of the Needle-leaved Evergreen subclass in the North. Though black spruce is common on nutrient-poor soils, Northern white cedar (*Thuja occidentalis*) dominates northern wetlands on more nutrient-rich sites. Along the Atlantic Coast, Atlantic white cedar (*Chamaecyparis thyoides*) is one of the most common dominants on organic soils. Pond pine is a common needle-leaved evergreen found in the Southeast in association with dense stands of broad-leaved evergreen and deciduous shrubs.

Scrub/Shrub

Definition. Scrub-Shrub Wetland includes areas dominated by woody vegetation < 6 m (20 feet) tall. The species include true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions. All water regimes except subtidal are included.

Needle-leaved Evergreen.--The dominant species in Needle-leaved Evergreen Wetlands are young or stunted trees such as black spruce or pond pine (*Pinus serotina*).

Dead

Definition. Wetland areas dominated by dead evergreen woody vegetation. Like Dead Deciduous Woody Wetlands, they are most common in, or around the edges of, impoundments and beaver ponds. The same factors that produce Dead Deciduous Woody Wetlands produce Dead Evergreen Woody Wetlands.

Mixed

The Mixed Woody Wetland subclass includes all forest and shrub wetland areas where both evergreen and deciduous trees and shrubs grow and neither predominates. When evergreen and deciduous species each respectively occupy > 33 percent of an area, the land it is classified as Mixed Woody. The Mixed Woody category is subdivided into two additional categories: Forest, and Scrub/Shrub.

Forest

This category includes all forested areas where both evergreen and deciduous trees are growing and neither predominate.

Scrub/Shrub

This category includes all shrub areas where both evergreen and deciduous shrubs are growing and neither predominate.

Dead

Wetland areas dominated by dead mixed woody vegetation. Like Dead Deciduous Woody Wetlands, they are most common in, or around the edges of, impoundments and beaver ponds. The same factors that produce Dead Deciduous Woody Wetlands produce Dead Mixed Woody Wetlands.

Water

Cowardin et al. (1979) define deepwater habitats as permanently flooded lands lying below the deepwater boundary of wetlands. Deepwater habitats include environments where surface water is permanent and often deep, so that water, rather than air, is the principal medium within which the dominant organisms live, whether or not they are attached to the substrate. As in wetlands, the dominant plants are hydrophytes. However, the substrates are considered nonsoil because the water is too deep to support emergent vegetation.

The class Water includes Marine/Estuarine, Lacustrine, Palustrine, and Riverine Deepwater subclasses as defined by Cowardin et al. (1979).

Appendix 5.

C-CAP Workshops

This guidance document results from the participation of more than 250 scientists, technical specialists, managers, and regional experts in nine protocol development workshops. Four regional workshops were held in the Northeast, Southeast, West Coast, and Great Lakes to address a broad range of issues including those specific to each major coastal region. Participation was encouraged across all Federal and state agencies involved in coastal research, management, and policy and many other agencies concerned with remote sensing and land cover analysis. The seagrass workshop followed the same format focusing specifically on submersed habitats. Each workshop was presented a draft C-CAP protocol, based initially on the Chesapeake Bay Prototype, and participants were encouraged to refine the draft and resolve remaining issues. Issues not resolved in the five major workshops were addressed through dedicated topical workshops. Finally, the issues which could not be resolved through workshops were explored through research funding proposals.

Two accuracy assessment workshops involved leading specialists in spatial error estimation who were asked to recommend protocols for accuracy assessment of C-CAP TM data. The accuracy assessment procedures outlined in this report are a direct result of those workshops. The classification workshop was a multi-agency group organized to develop a classification system that would suit C-CAP needs. Through the workshop and a long iterative process thereafter, the classification presented in this report was developed. The Maryland Field Reconnaissance workshop was unique in that the organizers were not from C-CAP but from the Maryland Department of Natural Resources and Salisbury State University. The principal objective of the workshop was to provide recommendations concerning C-CAP products. The reconnaissance consisted of field visits to sites in the vicinity of Salisbury, Maryland, identified in a preliminary version of the C-CAP Chesapeake Bay Land Cover Change Database. In addition, the preliminary C-CAP data were compared with other types of ancillary data supplied by workshop participants.

Findings and recommendations from these workshops and from other specialist meetings (not listed here) were crucial in the development of this document.

- Southeast Regional Workshop
Location: University of South Carolina
Columbia, South Carolina
Dates: May 29-31, 1990
Host: University of South Carolina

Co-Chairs: Dr. Jerome Dobson
Mr. Kenneth Haddad

- Seagrass Mapping Workshop
Location: Embassy Suites, Tampa Airport Hotel
Tampa, Florida
Dates: July 23-25, 1990
Co-Chairs: Dr. Randolph Ferguson
Dr. Robert Orth
- Accuracy Assessment Workshop Location: National Marine Fisheries Service
Beaufort Laboratory
Beaufort, North Carolina
Date: September 25, 1990
Host: Beaufort Laboratory
Chair: Dr. Jerome Dobson
- Northeast Regional Workshop
Location: Whispering Pines Conference Center
W. Alton Jones Campus
University of Rhode Island
Kingston, Rhode Island
Dates: January 8-10, 1991
Host: University of Rhode Island
Co-Chairs: Dr. Jerome Dobson
Mr. Kenneth Haddad
- Classification Scheme Workshop
Location: Silver Spring, MD
Date: February 12, 1991
Co-Chairs: Dr. James Johnston
Dr. Vic Klemas
- West Coast Regional Workshop
Location: Embassy Suites Hotel
Seattle, Washington
Dates: April 29 - May 1, 1991
Co-Chairs: Dr. Jerome Dobson
Mr. Kenneth Haddad
- Maryland Field Reconnaissance Workshop
Location: Salisbury State University
Salisbury, Maryland
Dates: July 16-18, 1991
Host: Salisbury State University
Workshop Design: Mr. William Burgess, Maryland Department of Natural Resources;
 - Dr. Edward W. Christoffers, NOAA/NMFS
 - Dr. Jerome Dobson, Oak Ridge National Laboratory
 - Dr. Randolph Ferguson, NOAA/NMFS
 - Dr. Adam Fisch, Virginia Council on the Environment

- Dr. K. Peter Lade, Salisbury State University
- Dr. James Thomas, NOAA/NMFS
- Dr. Bill Wilen, U.S. FWS, National Wetlands Inventory

Sponsors: Salisbury State University, Maryland Department of Natural Resources, NOAA and U.S. FWS

- Accuracy Assessment Workshop
Location: Oak Ridge National Laboratory
Oak Ridge, Tennessee
Date: August 1-2, 1991
Host: Oak Ridge National Laboratory
Chair: Dr. Jerome Dobson
 - Great Lakes Regional Workshop
Location: Best Western Ann Arbor Regent
Ann Arbor, Michigan
Dates: August 27-19, 1991
Host: NOAA's Great Lakes Environmental Research Lab
Co-Chairs: Dr. Jerome Dobson
Mr. Kenneth Haddad
-

Appendix 6.

C-CAP Protocol Development Research

C-CAP funded research to refine various aspects of the protocol based on workshop recommendations and on findings of the upland and wetland prototype (Chesapeake Bay), the water and submerged land prototype (North Carolina Coast), and the Salisbury field experience. These research projects are intended to increase the geographical coverage of the C-CAP change detection database. The following is a list of the institutions performing the research and the topics addressed in FY 91:

- University of South Carolina
 - Test change detection methodologies
 - Identify optimum pattern recognition algorithms
- North Carolina State University
 - Develop a seamless database from two independently developed land cover databases derived from TM data
- Universities of Rhode Island and Connecticut
 - Test change detection methodology
 - Test the use of available digital wetlands data as an aid for classifying TM imagery
- Beaufort NMFS
 - Develop change detection methodologies for SAV
- An announcement of availability of funds for protocol development research was distributed in March, 1992. The following five (5) studies were funded:
 - University of South Carolina

- Determine the impact of tides on coastal change detection
- North Carolina State University
 - Develop methodologies for accuracy assessment for change detection databases
- University of Virginia
 - Examine influence of tides on TM data with the aid of digital elevation models
- University of Maine
 - Develop improved methodologies for detecting forested wetlands
- University of New Hampshire
 - Develop methodologies for accuracy assessment of change detection databases

Two other studies were also funded by C-CAP in FY92:

- Universities of Rhode Island and Connecticut
 - Funded for six months to finish work started in 1991
 - Beaufort NMFS
 - Develop change detection methodologies for SAV using Global Positioning System (GPS) technology.
-

Appendix 7.

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Appendix 8.

Addendum to NOAA Technical Report NMFS/123

NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation, April 1995

JE Dobson, EA Bright, RL Ferguson, DW Field, LL Wood, KD Haddad, JR Jensen, H. Iredale, VV Klemas, RJ Orth, and JP Thomas

C-CAP was established to inventory coastal submersed habitats, wetland habitats, and adjacent uplands and monitors changes in these habitats on a one- to five-year cycle (Dobson, et. al., 1995). The C-CAP classification scheme and protocol is a product of a national panel of research scientists and resources managers, each ensuring that the unique features of their region are represented and that the system and procedures meet their specific information requirements. The protocol is a working document. As lessons are learned from C-CAP projects, user needs expand, and new techniques are adopted the C-CAP

standards will evolve. Following are clarifications to the protocol and suggested standard procedures that will benefit NOAA staff in the evaluation and distribution of project deliverables.

Land Cover Mapping

The C-CAP classification system, as presented in the protocols, needs clarification. When performing land cover analysis specific classes from the *Upland* and *Wetland* superclasses are required (underlined in the protocol, table attached). These classes include Developed Land, Cultivated Land, Grassland, Woody Land, Bare Land, Estuarine Emergent Wetland, Estuarine Woody Wetland, Palustrine Emergent Wetland, Palustrine Woody Wetland, and Water. Within each of the woody classes it will also be required that the subclass' Forest and Scrub/Shrub be identified (where they exist). Upland Woody Scrub/Shrub is required.

Submerged Aquatic Vegetation Mapping

When performing SAV mapping the protocol requires that the classes Water and Marine/Estuarine Aquatic Bed and the subclass Rooted Vascular seagrass be identified. In addition, to the extent possible, the Algal subclass (drift algae) should be mapped. Rather than just mapping the presence/absence of these vegetation classes, an attempt should be made to define sparse cover (<50%).

When collection training site data or performing an accuracy assessment the protocol calls for a grid sampling technique. C-CAP currently collects training site data via visual analysis. Accuracy assessment points are derived from a stratified random sample based on bathymetry

Deliverables

Project deliverables to C-CAP include

- baseline classified scene (time 1),
- secondary classified scene (time 2),
- change image with statistics, and
- appropriate metadata.

Additionally, any field reference data collected, ancillary data used, or accuracy statistics that are

generated should be delivered. For SAV mapping projects C-CAP will need copies of imagery and/or photography. Send hard copy materials to C-CAP for reproduction.

Preferred deliverable data format:

- Imagery: ERDAS Imagine
- Vector data: ArcInfo Interchange
- Projection: UTM meters (default to dominant zone)
- Datum: NAD27 or NAD83 - be consistent
- Tabular data: dbase4

Image processing guidelines:

- Process the entire scene
- Don't mosaic
- Do not filter the classification (<8 pixel majority in a 3 x 3 filter)

Notes on Producing a Successful C-CAP Product

- Prior to starting a C-CAP project, review the protocol!
- Read the introduction.
- Be familiar with the classification system (Chapter 2 and Appendix 3).
- Identify the land cover and SAV classes that will be relevant for the study area.
- Before selecting imagery, pay special attention to the first two sections of Chapter 3:

Remote Sensing System Considerations

Important Environmental Characteristics.

- Follow the initial image processing procedures outlined in section three or Chapter 3:

Image Processing Data to Inventory Upland and Wetland Change.

- Refer to Chapters 3 and 4 for classification and change detection guidelines.
- Conform to the quality assurance and control standards stated in Chapter 4.
- Call Shan Burkhalter or Don Field with questions or problems:

Shan Burkhalter, TPMC at NOAA CSC, shan.burkhalter@noaa.gov

Dr. Dorsey Worthy, CCAP National Coordinator, dorsey.worthy@noaa.gov

NOAA Coastal Change Analysis Program (C-CAP)

Phone: (843) 740-1200

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2234 South Hobson Avenue
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C-CAP Coastal Land Cover Classification System

Required classes noted in protocol.

Classes that should also be included where they exist.

1.0 Upland

1.1 Developed Land

- 1.11 **High Intensity**
- 1.12 **Low Intensity**

1.2 Cultivated Land

- 1.21 Orchards/Groves/Nurseries
- 1.22 Vines/Bushes
- 1.23 **Cropland**

1.3 Grassland

- 1.31 Unmanaged
- 1.32 Managed

1.4 Woody Land

- 1.41 Deciduous
- 1.411 **Forest**
- 1.412 **Scrub/Shrub**
- 1.42 Evergreen
- 1.421 **Forest**
- 1.422 **Scrub/Shrub**
- 1.43 Mixed
- 1.431 **Forest**
- 1.432 **Scrub/Shrub**

1.5 Bare Land

1.6 Tundra

1.7 Snow/Ice

- 1.71 Perennial Snow/Ice
- 1.72 Glaciers

2.0 Wetland

2.1 Marine/Estuarine Rocky Shore

- 2.11 Bedrock
- 2.12 Rubble

2.2 Marine/Estuarine Unconsolidated Shore (Beach, Flat, Bar)

- 2.21 Cobble-gravel
- 2.22 Sand
- 2.23 Mud/Organic

2.3 Estuarine Emergent Wetland

- 2.31 Haline (Salt Marsh)
- 2.32 Mixohaline (Brackish Marsh)

2.4 Estuarine Woody Wetland

- 2.41 Deciduous
 - 2.411 Forest
 - 2.412 Scrub/Shrub
 - 2.413 Dead
- 2.42 Evergreen
 - 2.421 Forest
 - 2.422 Scrub/Shrub
 - 2.423 Dead
- 2.43 Mixed
 - 2.431 Forest
 - 2.432 Scrub/Shrub
 - 2.433 Dead
- 2.5 Riverine Unconsolidated Shore (Beach, Flat, Bar)
 - 2.51 Cobble-gravel
 - 2.52 Sand
 - 2.53 Mud/Organic
- 2.6 Lacustrine Unconsolidated Shore (Beach, Flat, Bar)
 - 2.61 Cobble-gravel
 - 2.62 Sand
 - 2.63 Mud/Organic
- 2.7 Palustrine Unconsolidated Shore (Beach, Flat, Bar)
 - 2.71 Cobble-gravel
 - 2.72 Sand
 - 2.73 Mud/Organic

2.8 Palustrine Emergent Wetland (Persistent)

2.9 **Palustrine Woody Wetland**

- 2.91 Deciduous
- 2.911 Forest
- 2.912 Scrub/Shrub
- 2.913 Dead
- 2.92 Evergreen
- 2.921 Forest
- 2.922 Scrub/Shrub
- 2.923 Dead
- 2.93 Mixed
- 2.931 Forest
- 2.932 Scrub/Shrub
- 2.933 Dead

3.0 **Water and Submerged Land**

3.1 **Water** (Bottoms and undetectable reefs, aquatic beds or nonpersistent emergent Wetlands)

- 3.11 Marine/Estuarine
- 3.12 Riverine
- 3.13 Lacustrine (Basin > 20 acres)
- 3.14 Palustrine (Basin < 20 acres)
- 3.2 Marine/Estuarine Reef

3.3 **Marine/Estuarine Aquatic Bed**

- 3.31 Algal (e.g., kelp)
- 3.32 **Rooted Vascular** (e.g., seagrass)
- 3.321 High Salinity (> 5 ppt; Mesohaline, Polyhaline, Euhaline, Hyperhaline)
- 3.322 Low Salinity (< 5 ppt; Oligohaline, Fresh)

3.4 Riverine Aquatic Bed

- 3.41 Rooted Vascular/Algal/Aquatic Moss
- 3.42 Floating Vascular

3.5 Lacustrine Aquatic Bed (Basin > 20 acres)

- 3.51 Rooted Vascular/Algal/Aquatic Moss
- 3.52 Floating Vascular

3.6 **Palustrine Aquatic Bed (Basin < 20 acres)**

- 3.61 Rooted Vascular/Algal/Aquatic Moss
- 3.62 Floating Vascular